Streamflow Forecasting for the Logan and Blacksmith Fork Rivers in Northern Utah

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STREAMFLOW FORECASTING FOR THE LOGAN AND BLACKSMITH FORK RIVERS IN NORTHERN UTAH

KENNETH A. MANGELSON

1968

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by

Kenneth A. Mangelson

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Kenneth A. Mangelson

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ABSTRACT

Streamflow Forecasting for the Logan

and Blacksmith Fork Rivers

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by

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Major Professor: Cleve H. Milligan
Department: Civil Engineering

Accurate streamflow forecasts have been recognized as being important by water users and others whose occupations and pursuits depend upon the supply of water from snow fed streams.

The streamflow forecasting equations for the important predictive periods, in particular the April through September and the May through September total flows, were developed in this study for both the Logan and Blacksmith Fork Rivers.

Multiple linear regression was used as a mathematical model in determining the streamflow forecasting equations. A correlation analysis was used to determine the importance of the variables used in the mathematical model. The results of this thesis indicate the importance of the use of computers in streamflow forecasting. The results show a considerable increase in the accuracy of streamflow forecasts over the published forecasts due to the fact that more variables could be included into the model without complicating the mathematical computations greatly.

Efforts to improve the forecasts and eliminate the deviations between the forecasted and observed flows by using soil moisture data were unsuccessful.

(107 pages)

INTRODUCTION

Purpose

The ability to forecast total streamflow, peak flows, and the late summer flows accurately, has been recognized as being important to water users and others whose occupations and pursuits depend upon the supply of water from snow fed streams (32 and 33).

A method for forecasting the flow of the Logan River at Logan, Utah, using Fourier Series and Multiple Regression as a mathematical model, has been developed and verified with good accuracy by Professor Cleve H. Milligan[1] (21) and Dr. Rex L. Hurst[2]. Professor Milligan has pointed out, however, that the accuracy of streamflow forecasting may be improved by the inclusion of more variables and by using multiple linear regression as a mathematical model. Such a technique is now possible because of the tremendous improvement in the speed and capacity of modern computers.

In this thesis, a method of forecasting streamflow for the Logan River and its extension to the Blacksmith For River, Utah,

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[1]Cleve H. Milligan, Professor of Civil and Irrigation Engineering, Utah State University, Logan, Utah.

[2]Rex L. Hurst, Head of the Department of Applied Statistics, Utah State University, Logan, Utah.

using multiple linear regression as a mathematical model is presented along with the possible inclusion of soil moisture as a correction factor.

Because the climatological data are not available in the Blacksmith Fork watershed, this thesis also provides a technique for using the available data from the Logan River watershed.

The mathematical computations for this thesis were done at the Utah State University Computer Center.

Objectives

1. To forecast the streamflow on the Logan River, Cache County, Utah, by using Multiple Regression as a mathematical model.

2. To forecast the streamflow on the Blacksmith Fork River, Cache County, Utah, by using Multiple Regression as a mathematical model.

3. To compare computed forecasts with published forecasts by the United States Weather Bureau.

4. To apply possible correction factors determined from soil moisture measurements.

REVIEW OF LITERATURE

The importance of streamflow forecasting has long been recognized. For this reason, much research has been done on the important factors and methods that may be applied to predicting streamflow. Many researchers have generally had the following as objectives when developing forecast equations:

1. To minimize the number of variables or factors to develop simple relationships that will minimize the computations.

2. To consider only the variables for which records are available in a given area. The idea here is that they will be more significant than variables outside the given area. This is not always true as can be shown by a correlation study of the variables.

3. To utilize only April 1 snow data. But in many areas the April 1 snow data does not account for all the runoff, and by utlizing only April 1 snow data many other important factors are not included.

The following is a brief summary of some methods used by researchers to improve their forecast studies by including other factors of obvious importance.

Nearly all of the researchers listed made some improvements in forecasting streamflow at the time of their research; but in the attempt to minimize the number of variables, the importance of some of the available data was lost. One of the important reasons for the limitation of the number of variables has been data with insufficient years of record to establish a trend. Another reason for not including more variables in forecasting equations has been the computational difficulties that arise when using more variables. In later years these problems have become less important. There are data available with longer years of record and the use of the computer reduces the computational work considerably.

The summary of factors other than April 1 snow data that researchers have included in their methods of streamflow forecasting is as follows:

1. Baseflow
    a. Peck (26) included February streamflow.
    b. Nelson, McDonald, and Barton (22) included November or February 1 runoff.
    c. Eagle (8) included October runoff.
    d. Parshall (24) included February runoff.
2. Temperature
    a. Johnson (18) and Gay (15) suggested a forecast of spring and summer temperatures to be used with other factors to predict streamflow.
    b. Koelzer (20) included cumulative temperature versus cumulative runoff as a correction factor.
    c. Work (32) included temperature departure from

normal as an index.

3. Precipitation

   a. Spring rainfall was included by Clyde and Work (5).

   b. Fall rainfall was included by Farrow (10) as a factor.

   c. Work, Wilm, and Nelson (33) included April and the first half of May rainfall.

   d. Chard (2) included mid-March to June rainfall.

   e. Polos (27) included a weighted value for precipitation for the September-June period.

4. Soil Moisture

   a. Soil moisture was included by Clyde and Work (5) and Clyde (3).

   b. Fok (11) included soil moisture as a factor.

   c. Stockwell (28 and 29) used soil moisture in water supply forecasting.

   d. Farnes, Nelson, and Freeman (9) used soil moisture as a correction factor of forecast errors.

5. Combination of Factors

   a. Precipitation, temperature, and basin characteristics were included by Fulcher (14).

   b. Hannaford (16) included April-June precipitation and April-September base flow.

   c. Fok (12) included a twelve month average for precipitation, temperature, and base flow.

d. Soil moisture deficiency in the fall and spring precipitation, particularly April and May, were included by Paget (23).

Some researchers have used the basic statistical procedure that is used in this thesis, that of multiple regression and correlation, but not to any great extent, particularly as far as the number of variables and the use of the computer is concerned. The multiple correlation analysis for streamflow forecasting was first introduced by Ford (13) in 1948. This type of analysis has also been used by Gay (15) for temperature forecasting, Fok (11 and 12) for streamflow forecasting and by others.

More recently, electronic computers have been used in making the multiple regression analysis. Hannaford (17) developed a digital river basin model and favorably compared his results with conventional forecasting methods. Johnson (19) and Codd and Farnes (6) used the electronic computer in their multiple regression forecast studies. They included in their model snow storage, precipitation, temperature, and soil moisture, factors that Croft (7) found to be important. Base flow is possibly more important than soil moisture since this information includes the effects of soil moisture.

In this thesis, an approach to the problem of streamflow forecasting similar to Johnson's (19) is utilized. The procedure is statistically sound and has the following advantages over previous procedures:

1. Data are available with more years of record.
2. More variables are incorporated into the mathematical model.
3. A modern high speed computer is used.

PROCEDURES

Collection and Arrangement of Data

1. The data that were collected and used for streamflow forecasting included:

   a. Streamflow data as published by the Geological Survey, United States Department of Interior in "Geological Survey Water-Supply Papers, Part 10, The Great Basin", with tailrace runoff included. The tailrace runoff is that portion of the river which is divided from its natural channel into service canals.

   b. Temperature data as published by the Weather Bureau, United States Department of Commerce in "Climatological Data for Utah".

   c. Precipitation data as published by the Weather Bureau, United States Department of Commerce in Climatological Data for Utah".

   d. Snow survey data as published by the Soil Conservation Service, United States Department of Agriculture in "Federal State Cooperative Snow Surveys and Water Supply Forecasts for Utah".

   e. Soil moisture data as collected by personnel working on Utah Agriculture Experiment Station Project 459 under the direction of Professor Cleve H. Milligan. The data used were from the Klondike Narrows and Tony Grove Ranger soil moisture stations.

All of these data were tabulated by water year (October 1 to September 30) from 1924 to 1967 except soil moisture where only ten years of record, 1958 to 1967, were available.

2. The published streamflow forecasting data were collected from:

a. Streamflow data as published by the Soil Conservation Service, United States Department of Agriculture in, "Federal State Cooperative Snow Surveys and Water Supply Forecasts for Utah".

b. Streamflow data as published by the Weather Bureau, United States Department of Commerce in "Water Supply Forecasts for the Western United States".

Consistency of the Collected Data

The consistency of the data is one of many factors which can directly influence the accuracy of streamflow forecasts. This has been recognized by Fok (12) who made a careful study to determine the consistency of the data and the effect that any changes in location of measuring stations or the number of samples taken would have upon the consistency of the data.

Consistency of streamflow data

The streamflow data for the Logan and Blacksmith Fork Rivers are complete for the study period and these records are consistent.

Consistency of temperature data

The temperature data collected at the Utah State University station, Logan, Utah, were used since this station has the longest consistent record.

Consistency of precipitation data

The station history of Richmond, Utah, for precipitation shows that this station had had no change of location since it was established, and its record is complete for the study years. Fok (12) previously made a double mass curve of the Richmond versus Logan precipitation which plotted as a linear relationship with good correlation between stations. The Richmond precipitation data were used both in the Logan and Blacksmith Fork Rivers prediction models because the Richmond station has a longer period of record than the Logan station. The high correlation between stations would permit using either station, however.

Consistency of snow survey data

Fok (12) plotted double mass diagrams of the data of one snow course against another to test the consistencies of the data.

He also made linear regression and correlation studies and found that in general there is a high degree of correlation between the snow course data.

In the case of Garden City Summit snow course, the data were corrected in 1963 by the Soil Conservation Service. These corrected data were used in this study. The period of record at Garden City Summit only goes back to 1931, and the data at this station are needed from 1924 to 1931. This was accomplished by determining the regression equation of the linear relationship between the Mount Logan and Garden City Summit snow course and extending this curve back to estimate the missing data for the years 1924 to 1931 (see Table 30). A double mass curve was plotted of Mount Logan versus Garden City Summit snow courses showing the linear relationship and the high degree of correlation ($r = .937$) that exists between these two snow courses (Figure 1).

The Mathematical Model

The mathematical model used in this study was based on a multiple linear regression analysis.

1. The streamflow forecasting equation.

The streamflow forecasting equation, using the antecedent flows, temperature, precipitation, and water content of the April 1 snow course data from the nine snow courses used in this model, is as follows:

$$Y_{1-8} = b_o + b_1r_1 + b_2r_2 + b_3r_3 + b_4r_4 + b_5r_5 + b_6r_6 + b_7r_7$$

$$+ b_8r_8 + b_9r_9 + b_{10}r_{10} + b_{11}r_{11} + b_{12}r_{12} + b_{13}t_1$$

$$+ b_{14}t_2 + b_{15}t_3 + b_{16}t_4 + b_{17}t_5 + b_{18}t_6 + b_{19}t_7$$

$$+ b_{20}X_1 + b_{21}X_2 + b_{22}X_3 + b_{23}X_4 + b_{24}X_5 + b_{25}X_6$$

$$+ b_{26}X_7 + b_{27}X_8 + b_{28}X_9 + b_{29}p_1 + b_{30}p_2 + b_{31}p_3$$

$$+ b_{32}p_4 + b_{33}p_5 + b_{34}p_6 + b_{35}p_7 \ . \ . \ .$$

where

$\hat{Y}_{1-6}$ = predicted streamflow for each month April through September

$\hat{Y}_7$ = predicted total May to September flow

$\hat{Y}_8$ = predicted total April to September flow

b_o = a constant (y-axis intercept)

$b_1, b_2, b_3, \ . \ . \ . \ . \ , b_{35}$ are the multiple linear regression coefficients

$r_1, r_2, r_3, \ . \ . \ . \ . \ , r_{12}$ are the antecedent monthly streamflow data, April through March

$t_1, t_2, t_3, \ . \ . \ . \ t_7$ are the antecedent monthly temperature data, October through April

$X_1, X_2, X_3, \ . \ . \ . \ X_9$ are the April 1 measurements of the water content of the snow courses that will be listed hereafter

$p_1, p_2, p_3, \ldots, p_7$ are the antecedent monthly precipitation data, October through April

2. Simultaneous equations for the determination of multiple regression coefficients.

In determining the regression coefficients (b_n) and the constants (b_o) use was made of the digital computer to solve for the regression coefficients from 43 simultaneous equations of the form of the following equation by inverting this 43 order matrix:

$$y_n = b_o + \sum_{i=1}^{12} \sum_{j=1}^{12} b_i r_j + \sum_{i=13}^{19} \sum_{j=1}^{9} b_i t_j + \sum_{i=20}^{28} \sum_{j=1}^{9} b_i X_j$$

$$+ \sum_{i=29}^{35} \sum_{j=1}^{7} b_i p_j \quad . \quad . \quad .$$

where

Y_n is the measured streamflow for the period of time in question

b_o = Y-intercept constant to be determined

$b_1, b_2, b_3, \ldots, b_{35}$ are the multiple linear regression coefficients to be determined

r_{1-12} = measured monthly antecedent streamflow

t_{1-7} = measured monthly antecedent temperature

X_{1-9} = April 1 snow course data (water content in inches)

p_{1-7} = measured monthly antecedent precipitation

The 43 years of record of each of the variables used (1924-1966) made it possible to solve 43 simultaneous equations involving 36 unknowns giving seven degrees of freedom in the model. However, for the Logan River model, the data of two of the nine snow courses were not used, Monte Cristo and Dry Bread Pond, resulting in a reduction of two variables and a subsequent increase of two in degrees of freedom of this model. The data of these two snow courses were not used since they were not in the Logan River watershed.

The following tabulation is included to give a more detailed explanation of the variables used in the mathematical model for predicting streamflow and for the solutions of the 43 simultaneous equations

<u>Antecedent Streamflow</u>:

r_1 = April	r_2 = May
r_3 = June	r_6 = September
r_7 = October	r_8 = November
r_9 = December	r_{10} = January
r_{11} = February	r_{12} = March

<u>Antecedent Temperature</u> (Averages for month):

t_1 = October	t_2 = November
t_3 = December	t_4 = January
t_5 = February	t_6 = March
t_7 = April	

<u>Snow Course Data for April:</u>

X_1 = Franklin Basin

X_2 = Tony Grove Lake

X_3 = Tony Grove Station

X_4 = Spring Hollow Lower

X_5 = Spring Hollow Upper

X_6 = Mount Logan

X_7 = Garden City

X_8 = Monte Cristo (used for Blacksmith Fork only)

X_9 = Dry Bread Pond (used for Blacksmith Fork only)

<u>Antecedent Precipitation</u> (Total for month):

p_1 = October $\quad$ p_2 = November

p_3 = December $\quad$ p_4 = January

p_5 = February $\quad$ p_6 = March

p_7 = April

The Solution of the Mathematical Model

The solution of the mathematical model for determining the multiple regression coefficients, "b_n" values of the streamflow forecasting equation, and the constants "b_o" were obtained by arranging the 43 simultaneous equations (one equation for each year of record) into a matrix. A transformation of each of the variables was previously made by subtracing a constant from each of the variables to make handling of the matrix easier and more accurate.

The computer determined the "b_n" and "b_o" values for each predictive period for the Logan and Blacksmith Fork Rivers. This involved an inversion of the 43-order matrix. Table 21 gives the values of "b_n" and Table 23 the values of "b_o" for each dependent variable $\hat{Y}$ for the Logan River. Table 25 gives the values of "b_n" and Table 27 gives the values of "b_o" for the Blacksmith Fork River. These values are based on all the variables that were defined in the model. Tables 22 and 26 list the values of "b_n" and Tables 24 and 28 list the values of "b_o" for the Logan and Blacksmith Fork Rivers respectively when the model was simplified to include the 15 most important variables, determined by the correlation analysis. In solving for the regression coefficients "b_n" and the "b_o" values, use was made of a stepwise deletion, multiple regression analysis with control on the dependent variable $\hat{Y}$, developed by Dr. Rex L. Hurst. In using this analysis, the computer solved for the "b_n" and "b_o" values using all the variables in the model, then it deleted the variable which had the least degree of significance, as measured by the correlation coefficient (r^2), and then recomputed the "b_n" and "b_o" values for the new model. This procedure was continued until all but one of the variables in the model were deleted and the "b_n" and "b_o" values were determined for each linear model after the deletion of a variable. In this stepwise deletion analysis, the correlation coefficient (r^2), sometimes called the coefficient determination, for each model was determined. This gave a measure of the accuracy or predictive power of the variables in the specific model.

This procedure of computing regression coefficients "b_n", y-axis intercepts "b_o", and correlation coefficients "r^2" for each model, was used on both the Logan and Blacksmith Fork Rivers.

Because of the speed at which the regression coefficients and the y-axis intercept constants could be computed, a number of different models were used on both rivers.

On the Logan River, all of the variables except the data from the two snow courses more adjacent to the Blacksmith Fork watershed, Dry Bread Pond, and Monte Cristo, and the April precipitation and temperature, were used in the model for forecasting each predictive period previously defined. The fifteen variables, unique for each predictive period, that were found to be most significant by the stepwise regression analysis were also used to predict the flow of each predictive period.

This same procedure was carried out on the Blacksmith Fork River using the data of the two additional snow courses as variables for predicting the flow of each predictive period. But in the case of predicting the flow for May, June, July, August, September, and the May-September total, two additional variables were used, the April precipitation and temperature. These two variables can have a pronounced affect on the flow for both the total and the monthly flow. This gives rise to the need for their inclusion.

After the predictions were made for each year and for each predictive period for both rivers, these predictions were compared with the measured streamflow and the deviations were determined both absolutely and as an error in per cent of the actual flow.

A summary of the important phases of the multiple regression analysis program written in Fortran IV for the computer at Utah State University by Dr. Rex L. Hurst now follows:

Phase 1: Arithmetic transformations were performed on the variables to create new variables.

Phase 2: Calculation of means, standard deviations, and simple correlation coefficients was performed.

Phase 3: (a) Inversion of the sum of squares and sum of products matrix.

(b) Calculation of regression coefficients and correlation coefficients.

(c) Stepwise deletion of variables.

Phase 4: (a) Predictions based on calculated regression coefficients and observed values.

(b) Deviations of predictions from observed values determined.

Examples of Application

Problem 1: To forecast the May through September, 1967, total residual streamflow for the Logan River, Utah, (Table 1).

Problem 2: To forecast the August 1966 residual streamflow for the Blacksmith Fork River, Utah, (Table 2).

Table 1. The 1967 Forecasted May through September Total Residual Streamflow for the Logan River, Utah

n	Variables	Uncode Value	Code Factor	Coded X^1	b_n	$X^1 b_n$
	Antecedent Stream Flow					
1	r_1	18030	1/10	1803	-0.653	-1177.359
2	r_2	33250	"	3325	1.892	6290.900
3	r_3	19860	"	1986	-1.273	-2528.178
4	r_4	12500	"	1250	2.481	3101.250
5	r_5	9540	"	954	0.219	208.926
6	r_6	7900	"	790	-3.547	-2802.130
7	r_7	7420	"	742	-22.900	-16991.800
8	r_8	6740	"	674	28.928	19497.472
9	r_9	6370	"	637	-31.147	-19840.639
10	r_{10}	6320	"	632	15.905	10051.960
11	r_{11}	5220	"	522	-12.442	-6494.724
12	r_{12}	6520	"	652	30.306	19759.512
	Antecedent Temperature					
13	t_1	48.3	1	48.3	382.331	18466.587
14	t_2	40.7	"	40.7	-89.604	-3646.883
15	t_3	22.8	"	22.8	-179.088	-4083.206
16	t_4	28.6	"	28.6	72.165	2063.919
17	t_5	31.9	"	31.9	301.755	9625.985
18	t_6	38.5	"	38.5	-418.471	-16111.134
	Snow Course Data (May 1)[b]					
19	X_1	34.0[c]	1		607.237	20646.058
20	X_2	46.8	"	46.8	-342.846	-16045.193
21	X_3	6.0[d]	"	6.0	478.356	2870.136
22	X_4	20.5	"	20.5	-295.241	-6052.441
23	X_5	33.9	"	33.9	381.100	12919.290
24	X_6	42.1	"	42.1	70.786	2980.091
25	X_7	22.5	"	22.5	-251.974	-5669.415
	Antecedent Precipitation					
26	p_1	0.87	1	0.87	550.488	478.925
27	p_2	1.20	"	1.20	-1117.124	-1340.549
28	p_3	1.79	"	1.79	553.726	991.170
29	p_4	1.71	"	1.71	38.150	65.237
30	p_5	0.48	"	0.48	-696.096	-334.126
31	p_6	2.67	"	2.67	-657.971	-1756.783

$b_o = -11,953.08$[a]

$$\sum_{n=1}^{31} b_n X^1{}_n = 25142.858$$

Table 1. Continued

The forecasted stream flow:

$$\hat{Y}_7 = (b_o + \sum_{n=1}^{31} b_n X^1{}_n)\ 10$$

$$\hat{Y}_7 = (-11953.08 + 25142.86)\ 10$$

= 131898 Acre feet

Actual measured stream flow

Y = 141400 Acre feet
Percent Error = 6.72%

---

[a]The b_n values and the b_o value for this predictive period were taken from Tables 21 and 23 respectively.

[b]The snow data used in this model was the data taken on May 1. This data was used because of the very wet and cold spring that occurred. Using the April 1 snow data the forecasted flow would be 116304 acre feet which is considerably below the actual flow of 141400 acre feet. The difference between those two values is apparently due to the large amount of precipitation in the form of snow that occurred after April 1 on the watershed.

[c]Estimated water content, Franklin Basin.

[d]May 1 water content plus the precipitation departure from the average for the month of April at this station, Tony Grove Ranger Station.

Table 2. The 1966 Forecasted August Residual Streamflow for the Blacksmith Fork River, Utah

n	Variables	Uncode Value	Code Factor	Coded X^1	b_n	$X^1 b_n$
	Antecedent Stream Flow					
1	r_1	19960	1/10	1996	0.012	23.952
2	r_2	24400	''	2440	0.082	200.080
3	r_3	13620	''	1362	0.584	795.408
4	r_4	9590	''	959	-1.815	-1740.585
5	r_5	8220	''	822	-0.191	-157.002
6	r_6	7500	''	750	5.789	4348.500
7	r_7	6930	''	693	-9.803	-6793.479
8	r_8	6210	''	621	7.282	4522.122
9	r_9	5590	''	559	-4.559	-2548.481
10	r_{10}	4980	''	498	2.740	1364.520
11	r_{11}	4430	''	443	1.195	529.385
12	r_{12}	6690	''	669	0.254	169.926
	Antecedent Temperature					
13	t_1	54.2	1	54.2	-21.290	-1154.026
14	t_2	41.9	''	41.9	-14.818	-620.874
15	t_3	22.5	''	22.5	9.926	223.335
16	t_4	25.8	''	25.8	7.209	185.992
17	t_5	23.5	''	23.5	9.647	226.705
18	t_6	35.6	''	35.6	-10.485	-373.266
19	t_7	46.0	''	46.0	-15.959	-734.114
	Snow Course Data					
20	X_1	22.2	1	22.2	20.313	450.949
21	X_2	29.8	''	29.8	-8.447	-251.721
22	X_3	7.5	''	7.5	-7.004	-52.530
23	X_4	9.6	''	9.6	19.968	191.693
24	X_5	21.8	''	21.8	-3.862	-84.192
25	X_6	25.2	''	25.2	-8.729	-219.971
26	X_7	14.8	''	14.8	-6.944	-102.771
27	X_8	23.2	''	23.2	-5.975	-138.620
28	X_9	14.7	''	14.7	27.477	403.912
	Antecedent Precipitation					
29	p_1	0.06	1	0.06	22.208	1.332
30	p_2	3.91	''	3.91	-2.985	-11.671
31	p_3	2.22	''	2.22	64.753	143.752
32	p_4	0.47	''	0.47	-1.185	-.557
33	p_5	1.24	''	1.24	10.322	12.799
34	p_6	1.11	''	1.11	-32.706	-36.304
35	p_7	1.26	''	1.26	-46.250	-58.275

Table 2. Continued

$$b_o = 1832.32^a \qquad \sum_{n=1}^{35} b_n X^1{}_n = -1284.084$$

The forecasted stream flow:

$$\hat{Y}_5 = (b_o + \sum_{n=1}^{35} b_n X^1{}_n)\ 10$$

$$\hat{Y}_5 = (1832.32 - 1284.08)\ 10$$

$$\hat{Y}_5 = 5482 \text{ Acre feet}$$

Actual measured stream flow:

Y = 5330 Acre feet
Percent Error = -2.85%

[a]The b_n values and the b_o value for this predictive period were taken from Tables 25 and 27 respectively.

DISCUSSION AND RESULTS

Discussion of the Variables Used in the Mathematical Models

In choosing the variables that were used in the mathematical models for both rivers, reference was made to other writers and investigators as to the variables they discovered were important in runoff predictions.

Since there were 43 years of record, this limited to something less than 43 the number of variables that could be used in the model. The antecedent runoff has been shown to be important in runoff predictions; therefore, it was used on a monthly basis. The antecedent, temperature, and precipitation has also been shown to be important and they were also included in the model on a monthly basis. The monthly mean temperature and monthly total precipitation were used. The April 1 snow course data were used for the stations within the watershed except in the case of the Blacksmith Fork River. Since no courses exist on the watershed, courses of nearby watersheds were used.

The use of data for particular months was somewhat arbitrary, but also justified to some extent by previous attempts to predict streamflow. Some separate studies were made on the influence of various combinations of variables. For example, a study of combining the past six months flow, the past year flow, and the past two years flow into new variables was made without any improvement in the predictive power as measured by the correlation coefficient. Also, a study was made as to the influence of combining the mid-winter flows and mid-winter precipitation. This reduced the variables and made it possible to include others. The result was a decrease in the correlation coefficient indicating a loss in the predictive power of the model. Apparently, when combining variables, some of the uniqueness of the variables is lost, as was shown in the case of combining monthly precipitation and combining monthly flows to create new variables.

In limestone formations, such as exists in the Logan and Blacksmith Fork Rivers watersheds, there is considerable holdover of runoff due to the low permeability of the limestone formation whcih is an indication that antecedent flows are a measure of future flows. This was shown to be the case, but apparently not to any great extent as was evidenced by combining the past 12 months and past 24 months to create new variables. The uniqueness of the variables suggests the use of weekly values or even daily values of antecedent temperature, precipitation, and runoff. This will introduce too many variables for the number of years of record available, and make it impossible to create a model that could be used to forecast streamflow.

Significance of the Variables

After the multiple regression deletion analysis was made, a listing of the variables in order of their significance or importance to the model was measured by the change in the correlation coefficient was made for both rivers. Table 24 lists the variables in order of importance with the correlation coefficients for two models on for each predictive period. Table 28 lists the same information for the Blacksmith Fork River.

Discussion of the Results

The analysis of the results of forecasting the streamflow on the Logan and Blacksmith Fork Rivers shows that this method has a high degree of accuracy for the 43 years of record (see Tables 3 and 4).

The U. S. Geological Survey classifies the general accuracy of its streamflow records in the following way (31):

Excellent . . . . . . within 5 per cent error[3]

Good . . . . within 10 per cent error

Fair . . . . within 15 per cent error

Poor . . . . greater than 15 per cent error

The results in this thesis were classified according to this classification of the accuracy of streamflow.

In high flows, the accuracy of the streamflow measuring devices is no better than 10 per cent. In Table 3 for the Logan River, the results for predicting flow for the important total flows,

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[3] The Geological Survey states that they are 95 per cent confident that when they classify a river excellent, for a given year of record, that the error between the actual flow and the measured flow is less than 5 per cent.

Table 3. Accuracy of Forecasts Summarized for the 43 years of Record (1924-1966)-Logan River

	No. of yrs. (31 variables)	Percent Accuracy	No. of yrs. (15 variables)
April	10	≤ 5	9
	12	5-10	9
	8	10-15	6
	13	>15	19
May	21	≤ 5	10
	11	5-10	10
	4	10-15	9
	7	>15	14
June	20	≤ 5	14
	10	5-10	11
	6	10-15	5
	7	>15	13
July	22	≤ 5	18
	17	5-10	13
	4	10-15	5
	0	>15	7
Aug.	28	≤ 5	--
	13	5-10	--
	2	10-15	--
	0	>15	--
Sept.	29	≤ 5	--
	11	5-10	--
	3	10-15	--
	0	>15	--
May-Sept.	25	≤ 5	--
	15	5-10	--
	3	10-15	--
	0	>15	--
April-Sept.	30	≤ 5	--
	9	5-10	--
	4	10-15	--
	0	>15	--

Table 4. Accuracy of Forecasts Summarized for the 43 years of Record (1924-1966)-Blacksmith Fork River

	No. of yrs. (33 variables)	No. of yrs. (35 variables)	Percent Accuracy	No. of yrs. (15 variables)
April	9	--	≤5	12
	15	--	5-10	14
	3	--	10-15	3
	16	--	>15	14
May	--	18	≤5	11
	--	8	5-10	13
	--	10	10-15	4
	--	7	>15	15
June	--	23	≤5	16
	--	10	5-10	8
	--	5	10-15	6
	--	5	>15	13
July	--	32	≤5	21
	--	10	5-10	17
	--	1	10-15	1
	--	0	>15	4
Aug.	--	26	≤5	18
	--	11	5-10	16
	--	6	10-15	4
	--	0	>15	5
Sept.	--	34	≤5	23
	--	9	5-10	14
	--	0	10-15	6
	--	0	>15	0
May-Sept.	15	29	≤5	12
	15	11	5-10	9
	3	3	10-15	7
	10	0	>15	15
April-Sept.	19	--	≤5	13
	9	--	5-10	12
	9	--	10-15	7
	6	--	>15	11

May-September and April-September, are very favorable. In both of these prediction periods, the flows can be predicted with an error of less than 10 per cent more than 90 per cent of the time.

Table 4 summarizes the results of predicting streamflow on the Blacksmith Fork River. Close observation indicates that there are differences in the predictive power for the two rivers. Forecasts of streamflow for the predictive periods is more accurate sometimes for the Logan River and vica versa. The reason for this discrepancy is not known except that there are additional variables used in the Blacksmith Fork model which could cause the difference. Fok (12) has shown that there is a high degree of correlation between the Logan and Blacksmith Fork Rivers which would lead to the conclusion that the predictive power for both models should be somewhat similar. Since the April precipitation and temperature data were used in the Blacksmith Fork River model exclusively, a study was made to determine the importance of these two variables. In Table 4 for the May-September total flow the results of the study is shown. Out of the 43 years of record, by the inclusion of these two variables, the accuracy of the predictions was increased from 30 to 40 years for an error of prediction of less than 10 per cent. In analyzing these variables, particularly the April precipitation, in many years there is a considerable amount of precipitation in the form of snow during April on the watershed. Since this is not measured on the snow courses on April 1, the amount of water contained in the snow can increase the total flow considerably. The temperature during April probably has a greater affect on the period at which the flow will occur thus affecting the monthly predictions but not the predictions for the total flow. A high temperature during the early spring will increase the early spring flow and reduce the late summer flow by melting the snow pack at a higher rate. A low temperature during the early spring will reduce the spring flow but increase the summer flow. This is because the equivalent water content of the snow will not be available in the early spring due to the lack of melting caused by the low temperatures. High temperatures during the summer will reduce the summer flow due to the increase of evapotranspiration and lower temperatures will have an opposite effect on the available water that will occur as streamflow. Apparently these conditions, large temperature deviations from the average during the summer, do not influence the flows greatly since the late summer flows were predicted with a high degree of accuracy as shown by Tables 3 and 4.

Tables 3 and 4 show the effect on the accuracy of the streamflow forecasts when the number of variables have been reduced to the 15 most significant variables for each predictive period for both rivers.

Predictions were made for each predictive period on the Logan River for all the variables in the model and for the 15 most significant variables and compared with actual flow with the per cent deviation determined for each year of record. These predictions with the per cent error are tabulated in Tables 5 through 12. Tables 13 through 20 contain the same information for the Blacksmith Fork River. Tables 11 and 12 for the Logan River and Tables 19 and 20 for the Blacksmith Fork River also contain the published forecasts made by the U. S. Soil Conservation Service and the U. S. Weather Bureau with the deviation in per cent from the actual.

In comparing the forecasts made by the two government agencies with the proposed method contained in this thesis, considerable improvement is realized by the proposed method over the other two. These forecasts for past years were made in 1967 and compared with the published forecasts made for that specific year during that year. The government agencies have also improved their methods of forecasting which should be remembered when comparing the forecasts made in this thesis with the published forecasts.

In this thesis, an effort was made to determine the importance of soil moisture data in forecasting streamflow. Since data with only ten years of record were available, it could not be included into the mathematical model directly. It was decided that the soil moisture data be used as a correction factor to be applied to the forecasted streamflow for a particular prediction period. An effort was made to determine a linear relation between the deviations of the total forecasted streamflow for the April through

September period and the observed flow and the average resistance reading of the new gypsum blocks (1 and 30) for the month of October the year before the flow was observed. The month of October was selected because this month showed the greatest variability in the resistance readings.

Figures 2 and 3 show the relation of the deviations versus the average October resistance reading in milliamperes for the Klondike Narrows and Tony Grove Range Station soil moisture station respectively. Table 32 gives this data.

No effort was made to determine, by statistical proceedures, the linear equations of these graphs because of the obvious lack of a relationship between these variables.

The reasons for this inability to use soil moisture data as a correction factor are not known completely. One reason might be that the information gained from these data is already included to a large degree in the antecedent streamflow or baseflow data which has already been included in the mathematical model. Another reason might be the relatively small number of years of record that are available.

The summarized results of this thesis are shown in Tables 3 and 4 which show the number of years in each classification of errors in forecasts.

In analyzing these results, the April predictions show the greatest occurance of significant errors followed by the May predictions. To reduce these errors of forecasts, a curvilinear relationship might have been developed which would fit the data better and give a higher correlation. But in considering the usefulness of April and May forecasts on the Logan and Blacksmith Fork Rivers, this is not necessary. On rivers where there exists considerable storage, the April and May flow would be important. On the Logan and Blacksmith Fork Rivers, the April and May flows would not be as important as the other months because of the lack of storage which would make water available later in the year. The important months, as far as water users served by these two rivers are concerned, are the late summer months of June, July, August, September, and the May through September period. The accuracy of the forecasts made for these predictive periods on the two rivers was quite high with a linear relationship among the variables established. And because of this, a curvilinear relationship was not developed in this study.

CONCLUSIONS

1. The method for streamflow forecasting by using linear multiple regression as a mathematical model can be used to forecast streamflow for the Logan and Blacksmith Fork Rivers with improved accuracy over previous forecasts.

2. The results of this method indicate that even though the Blacksmith Fork watershed had no available weather and snow survey data within its boundaries, a reliable streamflow forecast can be made from the use of data from adjacent watersheds.

3. The results from the analysis of the significance of the variables indicate that the antecedent flow, particularly the mid-winter flow, is an important factor in streamflow forecasting.

4. The importance of the antecedent temperatures and precipitation was also recognized from the analysis of the significance of variables.

5. From the analysis of the results of the Blacksmith Fork River, the importance of the mean temperature and the total precipitation during the runoff period, particularly April, was recognized.

RECOMMENDATIONS

1. Better relationships between variables might be established by using multiple curvelinear regression as a mathematical model instead of linear multiple regression. This could be determined by a new study.

2. Accuracy of a linear model could be increased by the use of new variables, the April mean temperature and April total precipitation. This further suggests predicting the May temperature and precipitation.

3. Since the April temperature and precipitation was used only in the models for Blacksmith Fork, these data should be extended for use in the forecasts on the Logan River for the predictive periods after April 30.

4. More study needs to be done on the usefulness of soil moisture in forecasting streamflow.

LITERATURE CITED

1. Cannel, G. H. Effect of drying cycles in changes in resistance of soil moisture units. Soil Sci. Soc. Amer. Proc. 22:379-382, 1958.

2. Chard, A. G. Forecasting Powell Lake runoff. Proc. Western Snow Conf., pp. 11-12. April 1956.

3. Clyde, George D. Soil moisture as an aid in forecasting runoff from snow-cover. Trans. Amer. Geophys. Union 21:871-873. 1940.

4. Clyde, George D. Benefits of snow surveying. Proc. Western Snow Conf., pp. 84-99. April 1951.

5. Clyde, G. D. and R. A. Work. Precipitation-runoff relationships as a basis for water-supply forecasting. Trans. Amer. Geophys. Union 24:43-49. 1943.

6. Codd, A. R. and P. G. Farnes. Application of the electronic computer to seasonal streamflow forecasting. Proc. Western Snow Conf., pp. 21-23. April 1960.

7. Croft, A. R. Some factors that influence the accuracy of water supply forecasting in the intermountain region. Trans. Amer. Geophys. Union. 27:375-388. 1946.

8. Eagle, H. C. Relation of fall streamflow to spring runoff. Trans. Amer. Geophys. Union 20:117-121. 1939.

9. Farnes, P. G., M. W. Nelson, and T. G. Freeman. Soil moisture forecasting. Proc. Western Snow Conf., pp. 6-14. April 1963.

10. Farrow, R. C. The influence of autumn rainfall on the runoff from the melting snow. Trans. Amer. Geophys. Union 20:121-124. 1939.

11. Fok, Y. K. Soil moisture as a factor in streamflow forecasting for the Logan River, Utah. M.S. thesis. Utah State University. 1961.

12. Fok, Y. S. Streamflow forecasting for the Blacksmith Fork River, Utah. M. S. thesis. Utah State University. 1959.

13. Ford, Perry M. Forecasting flood-season runoff. Proc. Western Snow Conf., pp. 133-150. April 1948.

14. Fulcher, Martin K. An approach to streamflow forecasting. Proc. Western Snow Conf., pp. 18-23. April 1953.

15. Gay, Robert W. Forecasting temperature and snow melt floods. Proc. Western Snow Conf., pp. 1-7. April 1952.

16. Hannaford, J. G. Multiple-graphical correlation for water-supply forecasting. Proc. Western Snow Conf., pp. 26-32. April 1956.

17. Hannaford, J. F. Development of a digital river basin model. Proc. Western Snow Conf., pp. 20-26. April 1964.

18. Johnson, Clifton W. Temperature forecasting at Logan River, Utah for the snow melt-runoff season. M. S. thesis. Utah State University. 1957.

19. Johnson, L. F. Use of the electronic computer for streamflow analysis. Proc. Western Snow Conf., pp. 15-20. April 1960.

20. Koelzer, Victor A. Cumulative snowmelt runoff distribution graphs and their use in runoff forecasting. Proc. Western Snow Conf., pp. 30-46. April 1951.

21. Milligan, Cleve H. The use of Fourier Series in streamflow forecasting. Proc. Western Snow Conf., pp. 45-52. April 1957.

22. Nelson, M. W., McDonald, and Barton. Base flow as a parameter in forecasting the April-June runoff. Proc. Western Snow Conf., pp. 61-68. April 1953.

23. Paget, Fred. A new forecasting curve for the Kaweah. Trans. Amer. Geophys. Union 27:389-395. June 1946.

24. Parshall, R. L. Forecast of runoff based on the water content of the watershed snow cover corrected by a factor involving fall flow of the stream. Proc. Western Snow Conf., pp. 157-165. April 1948.

25. Pearson, Gregory L. Hydraulic Engineer. Soil Conservation Service, Snow surveying and water supply forecasting. (Paper). State Engineers Office. Salt Lake City, Utah.

26. Peck. G. L. Low-winter streamflow as an index to the short and long-term carry over effects in water supply forecasting. Proc. Western Snow Conf., pp. 41-48. April 1954.

27. Polos, A. J. The use of precipitation and snow survey data in water supply forecasting. Proc. Western Snow Conf., pp. 30-35. April 1953.

28. Stockwell, H. J. Use of soil moisture resistance units in water supply forecasting. Proc. Western Snow Conf., pp. 35-38. April 1959.

29. Stockwell, H. J. Soil moisture data as a forecasting variable. Proc. Western Snow Conf., pp. 67-72. April 1965.

30. Taylor, S. A., D. D. Evans, and W. D. Kemper. Evaluating soil water. Utah Agr. Exp. Sta. Bull. 426. 67. Utah State University. 1961.

31. U. S. Geological Survey. Surface water technical memorandum. No. 67. 05. November 4, 1966.

32. Work, R. A. Adjusting forecast-curves for abnormal spring and summer temperatures. Trans. Amer. Geophys. Union 23:126-138. 1944.

33. Work, R. A., H. G. Wilm, and M. W. Nelson. Use of snow surveys in planning regulation of Columbia River floods. Proc. Western Snow Conf., pp. 1-29. April 1951.

APPENDIX A

Results

Table 5. Actual and Predicted Flows in Acre-feet for April, Logan River, 1924-1966

		Actual Flow	Prediction 31	Percent Error	Prediction 15	Percent Error
April						
1924	1	19400	15931	17.88	14516	25.20
	2	15800	12997	17.75	13498	14.58
	3	17700	18760	-5.98	18346	-3.65
	4	13900	13871	0.21	13749	1.09
	5	13900	12957	6.78	15285	-9.96
	6	11200	16475	-47.12	14854	-32.60
1930	7	16200	14024	13.41	14915	7.94
	8	7640	8227	-7.70	9013	-18.00
	9	15170	17817	-17.46	17932	-18.25
	10	10100	9479	6.15	9678	4.18
	11	12790	12143	5.06	10699	16.35
	12	11200	11834	-5.65	12840	-14.63
	13	24300	22890	6.03	20955	14.02
	14	10000	9350	6.50	10023	-0.23
	15	19650	19162	2.48	16935	13.81
	16	16890	17654	-4.52	15835	6.25
1940	17	9940	10900	-9.66	9223	7.22
	18	7070	9642	-36.40	10091	-42.80
	19	13390	11597	13.40	10271	23.20
	20	29360	25063	14.62	23583	19.70
	21	8730	5950	31.90	6914	20.80
	22	7280	5975	17.93	6353	12.72
	23	33360	30530	8.49	32035	3.98
	24	12780	16351	-28.00	15854	-24.10
	25	13430	13587	-1.17	12137	-9.63
	26	18610	20033	-7.65	22583	-21.30
1950	27	21820	22394	-2.62	22129	-1.42
	28	27260	28252	-3.64	25098	7.95
	29	20040	19488	2.75	19810	1.15
	30	11660	10385	-10.94	9815	15.82
	31	12530	13867	-10.65	13685	-9.22
	32	8040	8577	-6.69	10429	-29.70
	33	22630	19112	-15.50	19025	15.91
	34	11020	9210	16.41	10712	2.79
	35	12800	17494	-36.70	16159	-26.00
	36	12600	12799	-1.58	14786	-17.37

Table 5. Continued

	Actual Flow	Prediction 31	Percent Error[a]	Prediction 15	Percent Error
April					
1960 37	16150	16863	-4.41	18310	-13.38
38	7360	10515	-42.80	7793	-5.88
39	25910	22043	14.91	20563	20.60
1963 40	9530	8352	-12.35	10420	-9.35
41	9000	9954	-10.59	12649	-40.50
42	17600	23271	-32.20	25878	-47.00
1966 43	18030	18055	-0.14	18452	-2.34

[a] - Percent Error = $\frac{\text{Actual Flow - Predicted Flow}}{\text{Actual Flow}}$ ~~X 100~~

Table 6. Actual and Predicted Flows in Acre-feet for May, Logan River, 1924-1966

		Actual Flow	Prediction 31	Percent Error	Prediction 15	Percent Error
May						
1924	1	41500	40117	3.34	41592	-0.22
	2	42100	43026	-2.20	45498	-8.07
	3	28700	29036	-1.17	30020	-4.60
	4	35800	35337	1.29	36865	-2.97
	5	54100	48980	9.47	41802	22.70
	6	37400	38357	-2.56	35213	5.81
1930	7	25200	29081	-15.40	28077	-11.40
	8	16800	16611	1.12	19865	-18.23
	9	53930	55271	-2.49	52225	3.16
	10	24400	27599	-13.10	28861	18.27
	11	13040	11886	8.85	14038	-7.65
	12	29470	33320	-13.05	32803	-11.30
	13	72960	66678	8.61	64199	12.03
	14	38400	36419	5.16	35510	7.52
	15	43450	46555	-7.15	40967	5.73
	16	28660	36468	-27.20	34117	-19.02
1940	17	26550	28625	-7.81	23277	12.32
	18	21050	15522	26.20	17424	17.20
	19	20230	20496	-1.31	25467	-25.80
	20	45600	42482	6.84	44722	1.92
	21	26670	20750	22.20	19883	25.40
	22	27920	26714	4.32	20161	27.80
	23	48000	49414	-2.95	48761	-1.59
	24	43590	42725	1.98	43464	0.29
	25	46890	38163	18.60	36174	22.90
	26	42900	40623	5.30	43346	-1.04
1950	27	49110	48347	1.55	52552	-7.02
	28	51750	52099	-0.68	50428	2.56
	29	53190	54832	-3.09	54584	-2.62
	30	21640	21689	-0.23	23856	-10.21
	31	28260	26757	5.32	30954	-9.52
	32	29680	30513	-2.80	25071	15.53
	33	49230	45246	8.10	42064	14.54
	34	33790	38895	-15.00	40489	-19.84
	35	47220	52297	-10.75	52505	-11.18

Table 6. Continued

		Actual Flow	Prediction 31	Percent Error	Prediction 15	Percent Error
May						
1959	36	25700	24694	3.91	31433	-22.30
1960	37	30120	29194	3.08	31955	-6.10
	38	18040	21571	-20.60	20182	-11.88
	39	41400	40350	2.54	43521	-5.13
	40	31960	31668	0.91	28492	10.87
	41	30110	35066	-16.50	34704	-15.25
	42	40560	43094	-6.24	47022	-15.93
1966	43	33250	33575	-0.98	36172	-8.79

Table 7. Actual and Predicted Flows in Acre-feet for June, Logan River, 1924-1966

		Actual Flow	Prediction 31	Percent Error	Prediction 15	Percent Error
June						
1924	1	21400	24434	-14.17	28186	-31.70
	2	30500	34912	-14.45	35602	-16.71
	3	17100	18360	-7.38	17213	-0.66
	4	47600	41292	13.24	43560	8.48
	5	35200	35819	-1.76	29979	14.81
	6	40300	39057	3.08	39987	0.78
1930	7	25100	24512	2.34	25259	-0.63
	8	11700	13165	-12.51	14123	-20.70
	9	57490	55429	3.59	57985	-0.86
	10	48500	46648	3.82	42382	12.60
	11	8360	7036	15.85	53146	36.50
	12	37510	37142	0.98	29917	20.20
	13	51560	48501	5.93	47298	8.43
	14	31260	34394	-10.00	32401	-3.65
	15	40540	37656	7.12	41138	-1.47
	16	18260	19410	-6.30	21838	-19.60
1940	17	15980	19452	-21.70	20870	-30.60
	18	15740	18438	-17.10	20771	-31.90
	19	25430	20914	17.70	20966	17.53
	20	46440	55286	-19.05	55698	-19.95
	21	27360	26334	3.75	25427	7.08
	22	38920	38704	0.55	32370	16.84
	23	39200	37725	3.76	36774	6.19
	24	30270	27098	10.48	21344	29.50
	25	46160	42116	8.76	40137	13.05
	26	33130	31502	4.91	35596	-7.45
1950	27	68780	69118	-0.49	69618	-1.22
	28	46150	46026	0.27	43990	4.68
	29	45960	47109	-2.51	47341	-3.01
	30	41880	41496	0.92	41847	0.08
	31	17430	20654	-18.50	24258	-39.10
	32	28500	32159	-12.84	30167	-5.85
1956	33	41860	43237	-3.29	44134	-5.45
	34	49690	49017	1.35	45670	8.10
	35	38940	42046	-7.98	39119	-0.46
	36	29940	29527	1.37	33487	-11.85

Table 7. Continued

		Actual Flow	Prediction 31	Percent Error	Prediction 15	Percent Error
June						
1960	37	25580	19025	15.75	22303	1.23
	38	14510	13172	9.20	14868	-2.47
	39	32520	33294	-2.38	34407	-5.08
	40	29060	26855	7.60	32209	-10.83
	41	39160	41726	-6.66	41200	-5.22
	42	61800	60075	2.79	61091	1.15
1966	43	19860	19757	0.52	21785	-9.70

Table 8. Actual and Predicted Flows in Acre-feet for July, Logan River, 1924-1966

		Actual Flow	Prediction 31	Percent Error	Prediction 15	Percent Error
July						
1924	1	13800	14075	-1.99	13705	0.69
	2	18600	19620	-5.48	20848	-12.09
	3	11600	12663	-9.17	11911	-2.68
	4	25000	23300	6.80	23042	7.83
	5	19100	19299	-1.04	17071	10.61
	6	22200	20209	8.89	20226	8.90
1930	7	13900	15180	-9.21	15551	-11.88
	8	7400	8099	-9.45	8405	-13.58
	9	30580	29426	3.78	28986	5.22
	10	18600	19260	-3.55	18749	-0.80
	11	6340	6016	5.12	4826	23.90
	12	16910	17155	-1.45	15530	8.17
	13	23720	22428	5.45	23175	2.30
	14	17900	18599	-3.90	17284	3.44
	15	19620	20435	-4.15	21032	-7.20
	16	11990	12775	-6.55	13907	-16.00
1940	17	10150	10156	-0.06	11221	-10.55
	18	9800	10850	-10.72	12547	-28.05
	19	13790	11933	13.48	12403	10.00
	20	26090	28877	-10.69	28182	-8.02
	21	15280	13924	8.88	14980	1.96
	22	23580	21925	7.03	18883	19.90
	23	21850	20678	5.36	21719	0.60
	24	17320	15796	8.80	13732	20.70
	25	21040	21344	-1.45	21002	0.18
	26	18350	17736	3.34	18485	-0.74
1950	27	40020	39973	0.12	40861	-2.10
	28	24790	24677	0.46	25242	-18.25
1952	29	22500	23458	-4.26	23828	-5.90
	30	21980	21539	2.03	22000	-0.09
	31	12140	13102	-7.92	14185	-16.85
	32	15090	16682	-10.55	15942	-5.65
	33	18920	19312	-2.07	18724	1.04
	34	23570	24903	-5.66	23244	1.38
	35	17630	18012	-2.17	18290	-3.74
	36	14910	13509	9.39	14383	3.53

Table 8. Continued

		Actual Flow	Prediction 31	Percent Error	Prediction 15	Percent Error
July						
1960	37	12600	12184	3.30	13181	-4.61
	38	8160	7707	5.55	7600	6.87
	39	18020	18711	-3.83	19039	-5.64
	40	14340	13909	3.00	15619	-8.91
	41	22080	22783	-3.18	22268	0.85
	42	32370	31382	3.06	31101	3.92
1966	43	12500	12530	-0.24	13225	-5.80

Table 9. Actual and Predicted Flows in Acre-feet for August, Logan River, 1924-1966

		Actual Flow	Prediction 31	Percent Error
August				
1924	1	10600	10977	-3.56
	2	12600	12965	-2.90
	3	9060	9667	-6.70
	4	14900	13786	7.47
	5	13400	13162	1.77
	6	13700	13188	3.73
1930	7	10500	10808	-2.93
	8	6260	6305	-0.72
	9	16600	16434	1.00
	10	12470	12624	-1.23
	11	5420	5313	1.97
	12	10990	11403	-3.76
	13	15590	14653	6.02
	14	12290	12582	-2.38
	15	13570	13366	1.50
	16	9240	9879	-6.92
1940	17	7800	7887	-1.11
	18	7350	8289	-12.78
	19	9550	8385	12.19
	20	15050	16061	-6.72
	21	10680	9664	9.52
	22	14290	13464	5.78
	23	14730	14285	3.02
	24	12450	11695	6.07
1948	25	13980	13649	2.37
	26	13020	12546	3.64
1950	27	19790	20030	-1.21
	28	16140	16236	-0.59
	29	15130	15641	-3.38
	30	13500	13147	2.61
	31	8800	9453	-7.42
	32	10220	11228	-9.84
	33	12560	12655	-0.75
	34	13720	14570	-6.18
	35	12370	13079	-5.73
	36	10420	9679	7.11

Table 9. Continued

		Actual Flow	Prediction 31	Percent Error
August				
1960	37	9330	9079	2.69
	38	6330	6632	-4.77
	39	11920	11755	1.38
	40	10030	9840	1.89
	41	12930	13411	-3.72
	42	17520	17292	1.30
1966	43	9540	9576	-0.38

Table 10. Actual and Predicted Flows in Acre-feet for September, Logan River, 1924-1966

		Actual Flow	Prediction 31	Percent Error
September				
1924	1	8840	9297	-5.17
	2	10200	10475	-2.70
	3	7720	8075	-4.73
	4	11500	10720	6.78
	5	10600	10394	1.94
	6	11100	10677	3.81
	7	8480	8703	-2.63
	8	5260	5262	-0.04
	9	12490	12366	0.99
	10	9740	9830	-0.92
	11	4750	4767	-0.36
	12	8270	8617	-4.19
	13	11770	11116	5.56
	14	9490	9694	-2.15
	15	10240	10013	2.22
	16	7460	7996	-7.18
1940	17	6540	6529	0.17
	18	5850	6644	-13.60
	19	7420	6543	11.81
	20	11330	12090	-6.70
1944	21	8150	7399	9.23
	22	11020	10346	6.10
	23	11310	11074	2.08
	24	9760	9121	6.55
	25	10860	10680	1.66
	26	10840	10403	4.02
1950	27	14330	14519	-1.32
	28	12380	12449	-0.56
	29	11800	12157	-3.03
	30	10170	9877	2.88
	31	7090	7539	-6.34
	32	7780	8655	-11.25
	33	9620	9722	-1.06
	34	10410	11197	-7.55
	35	9810	10268	-4.66
	36	8400	7782	7.36

Table 10. Continued

		Actual Flow	Prediction 31	Percent Error
September				
1960	37	7770	7610	2.06
	38	5440	5610	-3.13
	39	10160	9977	1.80
	40	8490	8369	1.43
	41	9930	10162	-2.34
	42	13560	13370	1.40
1966	43	7900	7925	-0.32

Table 11. Actual and Predicted Flows in Acre-feet for May-September, Logan River, 1924-1966

		Actual Flow	Prediction	Percent Error	SCS Prediction	Percent Error	WB Prediction	Percent Error
May-Sept								
1924	1	96140	98676	-2.64				
	2	114000	120904	-6.05				
	3	74180	77774	-4.85				
	4	134800	124508	7.64				
	5	132400	127621	3.61				
	6	124700	121661	2.44				
1930	7	83180	88174	-6.00				
	8	47420	49487	-4.37				
	9	171090	168961	1.25				
	10	113700	115941	-1.97				
	11	37910	35000	7.68				
	12	103150	107409	-4.12				
	13	175600	163423	6.94				
	14	109340	111570	-2.04				
	15	127420	128099	-0.53				
	16	75610	86420	-14.30				
1940	17	67020	72622	-8.35				
	18	59790	59693	0.16				
	19	76420	68427	10.70				
	20	144510	154582	-6.96				
	21	88140	78086	11.40				
	22	115730	111185	3.84				
	23	135090	133158	1.43				
	24	111890	105246	5.94				
	25	138930	126010	9.31				
	26	118240	112889	4.53				

Table 11. Continued

	Actual Flow	Prediction	Percent Error	SCS Prediction	Percent Error	WB Prediction	Percent Error
May-Sept							
1950 27	192030	191979	0.03				
28	151210	151507	-0.20				
29	148580	153079	-3.03				
30	109170	107783	1.27				
31	73720	77564	-5.22				
32	91330	99440	-8.88				
33	132190	130105	1.58				
34	131180	138489	-5.57			133000	-1.39
35	125970	135773	-7.79			130000	-3.20
36	89370	85348	4.51			106000	-18.62
1960 37	82400	77058	6.48	97000	-20.15	87000	-5.59
38	52480	54909	-4.64	79000	-50.60	59000	-12.23
39	114020	114180	-0.14	124000	-8.71	119000	-4.79
40	93880	90601	3.49	92000	2.00	108000	-15.06
41	114210	123186	-7.85	110000	3.69	100000	13.63
42	165810	165296	0.31	170000	-2.53	165000	0.49
1966 43	83050	83357	-0.37	70000	15.70	77000	7.29

SCS=Soil Conservation Service
WB =Weather Bureau

Table 12. Actual and Predicted Flows in Acre-feet for April-September, Logan River, 1924-1966

		Actual Flow	Prediction	Percent Error*	SCS Prediction	Percent Error	WB Prediction	Percent Error*
Apr-Sept								
1924	1	115540	114606	0.81				
	2	129800	133899	-3.16				
	3	91880	96553	-5.00				
	4	148700	138381	6.94				
	5	146300	140577	3.91				
	6	135900	138130	-1.64				
1930	7	99380	102202	-2.84				
	8	55060	57714	-4.81				
	9	186260	186779	-0.28				
	10	123760	125385	-1.31				
1934	11	50700	47142	7.02				
	12	114350	119245	-4.28	100000	13.75		
	13	199960	186311	6.83	190000	4.98		
	14	119340	120918	-1.32	119400	-0.05		
	15	147070	147265	-0.13	128000	12.95		
	16	92500	104078	-12.50	98000	-5.95		
1940	17	76960	83521	-8.53	80000	-3.96		
	18	66860	69332	-3.70	79000	-18.18		
	19	89810	79842	11.10	90000	-0.21		
	20	173870	179641	-3.32	190000	-9.30		
	21	96870	84033	13.28	85000	12.25		
1945	22	123010	117159	4.75	108000	12.20		
	23	168450	163686	2.83	150000	11.00		
	24	124670	121597	2.46	110000	11.80		
	25	152360	139598	8.36	120000	21.20		
	26	136850	132923	2.87	148000	-8.20		

Table 12. Continued

		Actual Flow	Prediction	Percent Error*	SCS Prediction	Percent Error*	WB Prediction	Percent Error*
Apr-Sept								
1950	27	213850	214374	-0.25	180000	15.90		
	28	178470	179760	-0.72	166000	7.00		
	29	168620	172568	-2.34	195000	-15.60		
	30	120830	118169	2.07	102000	15.60		
	31	86250	91428	-6.00	119000	-38.00		
	32	99370	108017	-8.70	108000	-8.70		
	33	154820	149218	3.62	150000	3.10		
	34	142200	147700	-3.86	153000	-7.60	118000	17.01
	35	138770	153267	-10.45	163000	-17.50	154000	-11.00
	36	101970	98146	3.76	116000	-13.80	118000	-15.75
1960	37	98550	93922	4.70	112000	-13.60	107000	-8.57
	38	59840	65426	-9.32	95000	-58.60	83000	-38.70
	39	139930	136227	2.65	150000	-7.20	156000	-11.50
	40	103410	98953	4.31	82000	20.70	98000	5.24
	41	123210	133141	-8.05	117000	5.10	107000	13.15
	42	183410	188565	-2.76	190000	-3.60	173000	5.68
1966	43	101080	101412	-3.28	89000	11.90	119000	-17.75

Table 13. Actual and Predicted Flows in Acre-feet for April, Blacksmith Fork River, 1924-1966

	Actual Flow	Predicted Flow (33 variables)	Percent Error	Predicted Flow (15 variables)	Percent Error
1924	12700	10629	16.30	11677	8.06
25	13400	11625	13.25	13025	2.80
26	10200	8966	12.10	8038	21.20
27	12500	13023	-4.18	13091	-4.73
28	12000	16191	-34.90	15468	-28.90
29	10400	7628	26.60	8612	17.20
1930	8570	9241	-7.83	8396	2.03
31	3800	4183	-10.00	3939	-3.66
32	17600	17568	0.18	18302	-3.99
33	7260	6598	9.10	7495	-3.24
34	3840	2684	30.10	2422	36.90
35	7600	8033	-5.70	8101	-6.60
36	24170	22743	5.90	22973	4.96
37	9590	11207	-16.86	10081	-5.13
38	15670	13285	15.23	14523	7.32
39	9050	8331	7.95	8207	9.32
1940	5520	4531	17.90	5144	6.81
41	3860	5548	-43.70	5707	-47.80
42	6750	8838	-31.00	9476	-40.40
43	20690	21299	-2.94	20357	1.61
44	5530	3832	30.70	4064	26.50
45	5570	6661	-19.60	5567	0.05
46	33680	3055	9.30	29491	12.41
47	9360	10139	-8.32	11163	-19.30
48	12680	11619	8.38	10613	16.31
49	16850	17139	-1.71	18284	-8.51
1950	22760	24838	-9.13	22627	0.59
51	24010	22560	6.03	22100	7.95
52	24350	23524	3.40	23197	4.74
53	8740	10325	-18.15	8077	7.60
54	10280	10440	-1.56	10946	-6.49
55	6620	8703	-12.74	8764	-13.52
56	20380	19344	5.09	20604	-1.10
57	10490	10797	-2.92	11425	-8.92
58	11120	15998	43.80	18681	68.00
59	8650	8530	1.39	8029	7.18

Table 13. Continued

	Actual Flow	Predicted Flow (33 variables)	Percent Error	Predicted Flow (15 variables)	Percent Error
1960	10160	9582	5.70	9604	5.48
61	4360	6363	-45.80	7161	-64.30
62	21930	20558	6.26	19177	12.53
63	7090	4131	41.80	3711	47.70
64	8000	7835	2.06	6720	16.00
65	19960	21229	-6.35	21436	-7.40
66	12180	14177	-16.40	14543	-19.45

Table 14. Actual and Predicted Flows in Acre-feet for May, Blacksmith Fork River, 1924-1966

	Actual Flow	Prediction 35	Percent Error	Prediction 15	Percent Error
May					
1924	14700	16276	-10.71	14881	-1.23
25	15700	16951	-7.97	16914	-7.74
26	7870	6084	22.70	4254	45.90
27	20200	20895	-3.44	21618	-7.02
28	19700	18625	5.45	16483	16.31
29	20100	17924	19.80	19996	0.52
1930	7870	9596	-21.90	9110	-15.75
31	4480	2741	38.80	3367	24.80
32	31900	32003	-0.32	32560	-2.07
33	13800	15142	-9.74	13737	0.47
34	3610	29658	17.81	3099	14.17
35	10500	10327	1.65	11425	-8.80
36	34810	33226	4.55	28695	17.52
37	21910	22176	-1.21	21660	1.14
38	16270	14683	9.75	13310	18.20
39	7530	8369	-11.14	10380	-37.80
1940	5440	6172	-13.48	6065	-11.50
41	5130	6045	-17.82	4851	5.45
42	6170	6840	-10.86	5755	6.73
43	14480	16402	-13.30	19678	-36.90
44	9190	9429	-2.60	12124	-32.00
45	11910	11695	0.97	12312	-4.24
46	22600	24000	-6.20	19802	12.39
47	12540	10605	15.41	11849	5.51
48	26870	25938	3.47	24543	8.65
49	16500	14754	10.59	17076	-3.49
1950	30760	30686	0.24	29767	3.23
51	26060	25502	2.14	25355	2.71
52	37160	37428	-0.72	38186	-2.76
53	11260	11301	-0.36	11992	-6.50
54	8360	8218	4.00	6874	19.69
55	15140	15520	-2.51	16151	-6.68
56	19290	20277	-5.12	20381	-5.66
57	20580	22488	-9.28	25649	-24.65
58	20760	21258	-2.40	18926	8.85
59	7890	7924	-0.43	9372	-18.80

Table 14. Continued

	Actual Flow	Prediction 35	Percent Error	Prediction 15	Percent Error
1960	9680	8243	14.85	10598	-9.48
61	4610	5341	-15.86	6050	-31.20
62	15820	16417	-3.77	17460	-10.35
63	10900	11602	-6.45	8313	23.70
64	17930	17455	2.65	17182	4.17
65	24400	21697	11.09	22702	6.95
66	11200	12462	-11.28	13179	-17.67

Table 15. Actual and Predicted Flows in Acre-feet for June, Blacksmith Fork River, 1924-1966

	Actual Flow	Prediction 35	Percent Error	Prediction 15	Percent Error
June					
1924	7680	8209	-6.89	8347	-10.11
25	8930	9328	-4.46	9467	-5.94
26	5380	4558	15.28	3426	36.30
27	10100	9789	3.08	10077	0.23
28	7740	8485	-9.64	8514	10.00
29	9820	8942	8.95	10032	-2.16
1930	3860	6046	-3.18	7260	-23.90
31	3500	3766	-7.60	2854	18.45
32	12000	11885	0.96	11729	2.26
33	10300	10086	2.08	9819	4.67
34	2970	3319	-11.75	1473	50.40
35	6250	5844	6.50	6922	-10.74
36	10940	11003	-0.58	10283	6.00
37	9470	9992	-5.51	8856	6.48
38	8910	8200	7.98	9016	-1.19
39	5230	5305	-1.43	6812	-30.30
1940	3770	3297	12.55	3594	4.67
41	3430	4033	-17.59	4853	41.50
42	4990	4840	3.00	5129	-2.79
43	8730	10108	-15.80	10616	-21.60
44	6530	5712	12.52	6501	0.44
45	12310	11361	7.70	10014	18.65
46	12270	11721	4.48	10065	18.00
47	7280	7627	-4.77	7934	-8.97
48	12050	12631	-4.82	11789	2.16
49	9710	9174	5.52	9845	1.39
1950	18770	18299	2.41	18022	3.99
51	13990	13472	3.71	14084	-0.67
52	16410	16126	1.73	14598	11.00
53	11040	11257	-1.96	12319	-11.58
54	5870	6908	-17.70	6662	-13.50
55	7440	9122	-22.60	9163	-23.20
56	10770	10740	0.28	9833	8.70
57	13140	13670	-4.03	12478	5.00
58	9240	9605	-3.95	10859	-17.50
59	5850	5969	-2.04	6898	-17.90

Table 15. Continued

	Actual Flow	Prediction 35	Percent Error	Prediction 15	Percent Error
1960	6260	5559	11.20	6028	3.71
61	3500	3054	12.75	2897	17.21
62	8350	8471	-1.45	8942	-7.09
63	6060	5666	6.50	5278	12.90
64	9520	9270	2.63	8852	7.01
65	13620	13402	1.60	13719	-0.73
66	7120	7240	-1.81	7138	-0.25

Table 16. Actual and Predicted Flows in Acre-feet for July, Blacksmith Fork River, 1924-1966

	Actual Flow	Prediction 35	Percent Error	Prediction 15	Percent Error
July					
1924	6640	7033	-5.92	7260	-9.35
25	7070	7271	-2.84	7411	-4.82
26	5140	4717	8.25	4292	16.51
27	6950	6959	-0.13	7152	-2.91
28	7010	7146	-1.94	6812	2.83
29	7010	6380	8.99	6833	2.53
1930	5320	5517	-3.70	5332	-0.23
31	3070	3083	-0.42	3234	-5.35
32	8360	8378	-0.22	9003	-7.78
33	6460	6498	-0.59	6114	4.36
34	2780	2872	-3.31	2839	-2.12
35	4280	4179	2.36	4418	-3.22
36	7860	7760	1.16	7769	1.16
37	6920	7093	-2.50	6894	0.37
38	7020	6681	4.83	6737	4.03
39	4370	4618	-3.67	4706	-7.69
1940	3280	3186	2.86	3235	1.37
41	2970	3218	-8.35	3074	-3.50
42	4090	3935	3.79	4058	0.78
43	6900	7480	-8.40	7599	-10.10
44	5340	4837	9.42	4808	9.96
45	7060	6683	5.34	5420	23.20
46	9240	9143	1.05	8342	8.54
47	6330	6441	-1.75	6408	-1.23
48	8300	8613	-1.33	7914	6.90
49	8140	7828	3.84	8714	-7.05
1950	11770	11578	1.63	11588	1.55
51	10920	10671	2.28	11343	-3.87
52	12110	12003	0,88	11394	5.91
53	7470	7554	-1.12	7577	-1.43
54	5160	5456	-5.80	5479	-6.19
55	5710	6464	-13.20	6640	-16.30
56	8580	8596	-0.19	8790	-2.45
57	9100	9420	-3.52	8547	6.07
58	7500	7650	-2.00	8121	-8.29
59	5070	5037	0.65	5175	-2.07

Table 16. Continued

	Actual Flow	Prediction 35	Percent Error	Prediction 15	Percent Error
1960	5110	4814	5.86	4751	7.03
61	3130	3038	2.94	3304	-5.56
62	6520	6599	-1.21	6685	-2.53
63	4770	4658	2.35	5571	-16.80
64	6650	6659	-0.13	6603	0.71
65	9590	9391	2.08	8671	9.58
66	6170	6293	-2.00	6714	-8.82

Table 17. Actual and Predicted Flows in Acre-feet for August, Blacksmith Fork River, 1924-1966

	Actual Flow	Prediction 35	Percent Error	Prediction 15	Percent Error
August					
1924	5870	5859	0.19	6032	-2.76
25	5510	5462	0.87	5453	1.03
26	4960	4510	9.07	4109	17.18
27	6460	6494	-0.53	6433	0.42
28	6400	6900	-7.81	5973	6.68
29	6210	5350	13.83	5858	5.67
1930	5440	5568	-2.36	5143	5.46
31	3090	3107	-0.55	2905	5.99
32	7260	7107	2.11	7286	-0.36
33	5380	5401	-0.39	5380	0.00
34	2710	2785	-2.77	2669	1.51
35	3720	3499	5.94	3805	-2.28
36	6590	6420	2.58	6185	6.15
37	5730	6154	-7.40	6075	-6.02
38	6140	5671	7.65	6192	-0.85
39	3920	3892	9.71	2981	-1.55
1940	3000	2841	4.96	2783	7.24
41	2820	3241	-14.91	3490	-23.80
42	3420	3440	-0.58	3478	-1.70
43	6100	6822	-11.83	6722	-10.20
44	4630	4130	10.70	4143	10.51
45	6180	5636	8.79	4709	23.80
46	7960	7393	7.12	7454	6.35
47	5740	5780	-0.70	5642	1.71
48	7300	4480	-10.69	5242	-21.15
49	7220	7402	-2.52	7658	-6.07
1950	10100	10072	0.28	9397	6.96
51	9810	9473	3.44	9914	-1.06
52	10230	10229	0.00	10203	0.26
53	6400	6411	-0.17	6783	5.99
54	4720	5397	-14.35	5639	-19.45
55	5160	5594	-8.40	5846	-13.30
56	7340	7278	0.85	7498	-2.16
57	7730	7898	-2.18	7392	4.38
58	6720	7158	-6.52	7132	-6.14
59	4900	4889	0.22	4435	9.50

Table 17. Continued

	Actual Flow	Prediction 35	Percent Error	Prediction 15	Percent Error
1960	4450	4259	4.29	4563	2.54
61	2870	3079	-7.28	3194	-11.30
62	5880	5788	1.56	6211	-5.63
63	4260	4020	5.63	4435	-4.11
64	5620	5467	2.72	5245	6.67
65	8220	8063	1.91	7638	7.08
66	5330	5471	-2.64	5576	-4.62

Table 18. Actual and Predicted Flows in Acre-feet for September, Blacksmith Fork River, 1924-1966

	Actual Flow	Prediction 35	Percent Error	Prediction 15	Percent Error
September					
1924	5500	5833	-5.87	5890	-7.09
25	5650	5853	-3.59	6031	-6.75
26	4410	4048	8.21	3837	13.00
27	5740	5708	0.56	5962	-3.87
28	5510	5607	-1.76	5569	-1.07
29	5730	5213	9.02	5352	6.60
1930	4670	4862	-4.11	5127	-9.80
31	2860	2669	6.68	2885	-0.88
32	5730	5731	-0.00	5858	-2.24
33	4720	4742	-0.47	4529	4.05
34	2570	2612	-1.63	2278	11.37
35	3290	3329	-1.18	3585	-8.97
36	5620	5504	2.06	5102	9.22
37	4960	5076	-2.33	4936	0.48
38	5400	5032	6.81	5154	4.66
39	3650	3808	-4.33	3900	-6.85
1940	2860	2747	3.95	2481	13.26
41	2590	2791	-7.77	2836	-9.50
42	3160	3215	-1.74	3258	-3.10
43	5130	5605	-9.26	5901	-15.00
44	4030	3669	8.96	4032	-0.05
45	5320	4107	4.00	4876	8.35
46	6690	6645	0.67	6457	3.49
47	5120	5098	0.43	5272	- 2.95
48	6170	6210	-0.65	5629	8.77
49	6320	6122	3.14	6561	-3.82
1950	8930	8817	1.26	8703	2.54
51	8390	8183	2.47	8053	4.02
52	8520	8560	-4.70	8261	3.04
53	5630	5742	-1.99	5877	-4.38
54	4290	4478	-4.39	4228	1.44
55	4590	4973	8.35	5145	-12.10
56	6300	6320	-0.32	6139	2.56
57	6760	7014	-3.76	6374	5.27
58	5880	5998	-2.01	6390	-8.68
59	4570	4471	2.16	4651	-1.77

Table 18. Continued

	Actual Flow	Prediction 35	Percent Error	Prediction 15	Percent Error
1960	3890	3812	2.00	3663	5.84
61	2800	2909	-3.89	3206	-14.51
62	5210	5152	1.11	5021	3.63
63	3840	3868	-0.73	3756	2.19
64	4830	4827	0.06	4609	4.58
65	7500	7391	2.78	7511	-0.15
66	4860	4941	-1.66	5305	-9.15

Table 19A. Actual and Predicted Flows in Acre-feet for May-September, Blacksmith Fork River, 1924-1966

	Actual Flow	Prediction 33	Percent Error	Prediction 15	Percent Error
May-Sept					
1924	40390	43841	-8.55	48050	-18.96
25	42860	45854	-6.99	47669	-11.21
26	27760	21947	21.00	22309	19.70
27	49450	47559	3.84	51944	-5.05
28	46360	47696	-2.88	38147	17.72
29	48870	40099	18.00	46479	4.90
1930	29160	30646	-5.10	28099	3.65
31	17000	10032	-17.25	19649	-15.58
32	65250	68997	-5.75	64084	1.78
33	40660	37694	7.30	43486	-6.95
34	14640	15164	-3.58	10413	28.90
35	28040	31274	7.12	25469	27.80
36	65820	62822	4.55	66207	-0.59
37	48990	48823	0.34	43907	10.40
38	43740	41517	5.09	39479	9.75
39	24700	29746	-20.40	28886	-16.95
1940	18350	19929	8.60	19695	-7.33
41	16940	12791	24.40	15566	8.11
42	21830	23730	-8.70	26880	-23.10
43	41340	51008	-23.40	55345	-33.90
44	29729	30683	-3.24	30735	-3.42
45	42680	39670	7.05	35553	16.70
46	58760	52518	10.60	51121	13.00
47	37010	35080	5.21	40913	-10.53
48	60890	51145	16.00	45956	24.60
49	47890	49311	2.97	42126	-8.85

Table 19 A. Continued

Year	Actual Flow	Prediction 33	Percent Error	Prediction 15	Percent Error
1950	80330	78305	2.52	74311	7.50
51	69170	67836	1.93	67761	2.04
52	84430	85610	-1.40	80088	5.14
53	41800	45123	-7.95	44579	-6.65
54	28600	34902	-22.00	37703	-31.80
55	38040	36776	3.32	36878	3.05
56	52280	54155	-3.59	52331	-0.10
57	57310	57517	-0.36	55347	3.43
58	50100	50099	0.00	56218	-12.20
59	28280	31941	-12.97	33754	-19.35
1960	29390	24431	16.90	24530	16.55
61	16910	18325	-8.35	28053	-65.80
62	41780	48532	-16.20	47240	-13.07
63	29830	28512	4.41	25954	13.00
64	44550	47221	-6.00	46399	-4.15
65	63330	57685	8.90	60234	4.89
66	34680	38706	-11.60	35595	-2.64

Table 19 B. Actual and Predicted Flows in Acre-feet for May-September, Blacksmith Fork River, 1924-1966

	Actual Flow	Prediction 35	Percent Error*	SCS Prediction	Percent Error*	WB Prediction	Percent Error*
May-Sept							
1924	40390	43462	-7.60				
25	42860	44846	-4.64				
26	27760	23860	14.07				
27	49450	50094	-1.30				
28	46360	46490	-0.28				
29	48870	44261	9.33				
1930	29160	31849	-9.23				
31	17000	15504	8.79				
32	65250	65290	-0.06				
33	40660	41874	-2.99				
34	14640	14561	0.54				
35	28040	31960	4.67				
36	65820	64082	2.64				
37	48990	50232	-2.54				
38	43740	40510	7.38				
39	24700	25870	-4.74				
1940	18350	18391	-0.22				
41	16940	19335	-4.93				
42	21830	22287	-2.09				
43	41340	46330	-12.08				
44	29720	28268	4.89				
45	42680	40577	4.94				

Table 19 B. Continued

	Actual Flow	Prediction 35	Percent Error	SCS Prediction	Percent Error	WB Prediction	Percent Error
1946	58760	59239	-0.81				
47	37010	35545	3.96				
48	60890	61088	-0.32				
49	47890	44691	6.68				
1950	80330	79295	1.29				
51	69170	67357	2.62				
52	84430	83933	0.59				
53	41800	42339	-1.29				
54	28600	30279	-5.87				
55	38040	41870	-10.00				
56	52280	53519	-2.37				
57	57310	60822	-6.13			56000	2.29
58	50100	51342	-2.48			65000	-30.15
59	28280	28404	-0.44			39000	-37.95
1960	29390	26053	11.33	37000	-25.90	29000	1.33
61	16910	16811	0.58	20000	-18.25	19000	-12.35
62	41780	42901	-2.68	51000	-22.10	45000	-7.70
63	29830	29683	0.49	37000	-24.00	45000	-34.05
64	44550	43570	2.20	47000	-5.56	34000	23.70
65	63330	59562	5.95	56000	+11.60	53000	16.64
66	34680	36905	-6.42	33000	+4.85	28000	19.25

Table 20. Actual and Predicted Flows in Acre-feet for April-September, Blacksmith Fork River, 1924-1966

	Actual Flow	Prediction 33	Percent Error	Prediction 15	Percent Error	SCS Prediction	Percent Error	WB Prediction	Percent Error
Apr-Sept									
1924	53090	54470	-2.60	57753	-8.79				
25	56260	57479	-2.16	56152	0.19				
26	37960	30913	18.55	33945	10.59				
27	61590	60582	2.21	62398	-0.72				
28	58360	63888	-9.50	54740	6.21				
29	59270	47728	19.50	52869	10.80				
1930	37730	39887	-5.70	41775	-10.70				
31	20800	24116	-15.90	23279	-11.90				
32	82850	86564	-4.48	85708	-3.45				
33	47920	44291	7.58	44111	7.95				
34	18480	17847	3.42	14069	23.90				
35	35640	39307	-10.30	31284	26.90	35000	1.79		
36	89990	85565	4.92	84198	6.44	82000	8.88		
37	58580	60030	-2.48	53911	7.96	58600	-0.03		
38	59410	54801	7.75	51850	12.75	80000	-34.66		
39	33750	38077	-12.83	41277	-22.30	45000	-33.33		
1940	23870	24460	-2.47	28616	-19.00	30000	-25.68		
41	20800	18339	11.83	19391	6.77	30000	-44.20		
42	28580	32568	-13.98	38268	-33.90	35000	-22.40		
43	62030	72307	-16.55	77142	-24.40	75000	-20.91		
44	35250	34514	2.09	38388	-8.89	27000	+23.40		
45	48250	46331	3.98	40043	17.00	40000	17.10		
46	92440	83064	10.15	81577	11.75	64000	35.10		
47	46370	45219	2.48	46877	-1.09	40000	13.20		
48	73570	62753	14.71	57151	22.30	46000	37.40		
49	64740	66449	-2.64	74962	-15.80	62000	4.24		

Table 20. Continued

	Actual Flow	Prediction 33	Percent Error	Prediction 15	Percent Error	SCS Prediction	Percent Error	WB Prediction	Percent Error
1950	103090	103143	-0.05	102653	0.42	75000	27.20		
51	93180	90397	2.99	89474	3.98	67500	27.60		
52	108780	109134	-0.33	101618	6.60	100000	8.08		
53	50540	55448	-9.70	51529	-1.95	32000	31.60		
54	38880	45342	-16.60	48402	-24.50	50000	-28.60		
55	45760	45479	0.61	48988	-7.19	53000	-15.80		
56	72660	73500	-1.16	69425	4.45	70000	3.66	59000	18.80
57	67800	68314	-0.76	71953	-6.14	38000	13.60	57000	15.95
58	61220	66097	-7.97	74950	-22.40	76000	-24.10	80000	-30.70
59	36930	40470	-9.59	38806	-5.08	47000	-29.00	50000	-35.40
1960	39550	34013	14.00	36791	7.00	52000	-31.50	41000	-3.68
61	21270	24688	-16.05	23824	-12.00	31000	-45.70	30000	-41.10
62	63710	69089	-8.45	62431	2.00	72000	-13.00	60000	5.83
63	36920	32643	11.60	35933	2.79	25000	32.40	36000	2.49
64	52550	55056	-4.77	55156	-4.96	56000	-6.55	34000	35.30
65	83290	78914	5.25	83594	-0.36	57000	19.60	68000	18.37
66	46860	52883	-12.88	49101	-4.79	49000	-4.56	53000	-13.10

Table 21. Regression coefficients "b_n" for the Logan River using 31 variables

	April	May	June	July	August	Sept	Total May-Sept	Total Apr-Sept
b_1	-0.225	-0.299	-0.294	0.015	-0.033	-0.031	-0.653	-0.877
b_2	-0.386	0.284	1.058	0.291	0.158	0.093	1.892	1.506
b_3	-0.022	-0.734	-0.258	-0.141	-0.105	-1.273	-1.273	-1.295
b_4	-0.135	0.986	1.277	-0.050	0.173	-0.077	2.481	2.344
b_5	-0.712	-0.143	0.252	0.106	0.031	-0.002	0.219	-0.493
b_6	6.026	2.562	-6.045	0.103	-0.211	0.199	-3.547	2.477
b_7	5.046	-7.343	-8.152	-4.501	-2.088	-1.288	-22.900	-17.847
b_8	-11.315	5.428	13.086	5.514	3.547	2.180	28.928	17.608
b_9	10.163	20.863	-25.689	-16.897	-5.819	-3.546	-31.147	-20.980
b_{10}	13.302	-27.775	20.839	15.557	4.541	2.518	15.905	2.601
b_{11}	3.239	-3.062	-5.730	-2.120	-1.249	-0.439	-12.442	-9.201
b_{12}	3.620	11.406	9.350	5.417	2.606	1.593	30.306	33.930
b_{13}	-36.081	63.530	156.763	91.440	43.373	26.729	382.331	346.338
b_{14}	8.745	5.007	-53.179	-20.012	-13.205	-8.978	-89.604	-80.867
b_{15}	1.752	-119.087	-40.424	-8.075	-7.100	-4.506	-179.088	-177.314
b_{16}	8.428	44.969	27.696	-2.367	1.928	-0.006	72.165	80.565
b_{17}	-3.126	84.260	119.591	59.634	25.984	12.718	301.755	298.715
b_{18}	-22.903	-113.027	-151.038	-89.711	-37.088	-23.399	-418.471	-441.497
b_{19}	-88.499	222.190	252.845	68.121	40.130	25.891	607.237	518.653
b_{20}	73.156	132.940	-146.381	-26.277	-25.594	-14.020	-342.846	-269.635
b_{21}	-49.854	140.760	201.371	78.410	42.804	22.014	478.356	428.444
b_{22}	72.395	-121.890	-125.888	-19.600	-18.109	-11.507	-295.241	-222.757
b_{23}	30.227	172.904	118.579	35.983	34.223	26.280	381.100	411.284
b_{24}	-47.759	-45.517	89.969	13.975	8.408	3.032	70.786	22.975
b_{25}	19.598	-47.700	-133.391	-41.353	-21.207	-12.737	-251.974	-232.318

Table 21. Continued

	April	May	June	July	August	Sept	Total May-Sept	Total Apr-Sept
b_{26}	63.067	277.262	117.154	112.061	37.829	11.949	550.488	613.700
b_{27}	339.935	-151.084	-509.277	-260.523	-127.582	-86.417	-1117.124	-776.922
b_{28}	-188.577	63.657	235.425	154.193	68.788	42.631	555.726	366.936
b_{29}	117.740	278.070	-75.503	095.107	-34.640	-37.545	38.150	155.988
b_{30}	246.976	413.545	-722.931	-258.857	-98.054	-45.317	-696.096	-448.816
b_{31}	44.906	206.713	-456.993	-241.598	-111.431	-71.180	-657.971	-613.069

Table 22. Regression coefficients "b_n" for the Logan River using the 15 most significant variables

	April	May	June	July	August	Sept	Total May-Sept	Total Apr-Sept
b_1	-0.301	-0.517						
b_2	-0.211	0.242	0.505	0.192	0.092	0.073	0.979	0.774
b_3						-0.009		
b_4								
b_5	-0.521							
b_6	3.333							
b_7	4.727		-2.280					-6.551
b_8	-8.947				0.349			
b_9	9.020	22.300	-18.768	-13.731	-4.712	-2.798	-32.723	-9.498
b_{10}	-14.664	-34.287	18.380	11.584	3.466	2.219	21.201	
b_{11}	4.797							
b_{12}	4.667	10.510	3.189	3.939	1.658	1.282	15.106	26.070
b_{13}			98.549	78.964	28.561	19.641	248.521	289.059
b_{14}			-31.348	-17.143	-12.963	-7.318	-118.079	
b_{15}		-95.197						-91.715
b_{16}		51.354						65.680
b_{17}		101.179	38.804	41.783	15.234	8.300	111.291	174.103
b_{18}		-111.766	-103.267	-75.346	-42.334	-29.308	-432.332	-389.040
b_{19}	-22.411	131.228	132.158	42.807	12.473	10.699	330.993	277.542
b_{20}		-105.148					-77.228	
b_{21}		80.376	85.565	36.849				199.709
b_{22}	81.260		-70.449				-169.362	
b_{23}		96.828			21.088	15.077	282.379	170.669
b_{24}								
b_{25}								-135.960

Table 22. Continued

	April	May	June	July	August	Sept	Total May-Sept	Total Apr-Sept
b_{26}		231.956		110.219				707.205
b_{27}	280.649		-189.354	-123.864	-53.513	-50.441	-469.760	-383.646
b_{28}	-92.442		261.012	120.067	22.853		218.822	
b_{29}	144.308	397.721				-37.448		
b_{30}			-544.292	-230.177	-78.199	-30.078	-548.224	
b_{31}				-114.957	-40.123	-36.170		

Table 23. The "b_o" value and correction factor for each predictive period for the Logan River, Utah

Predictive Period	With all 31 variables in the model "b_o"	correction factor[a]	With 15 most significant variables in the model "b_o"	correction factor
April 33	786.66	10	-1041.03	10
May	-3119.74	10	1358.30	10
June	-3608.14	10	-1292.18	10
July	-3177.74	10	-2433.64	10
August	-1369.65	10	19.36	10
Sept	-710.49	10	44.56	10
Total May-Sept	-11953.08	10	745.61	10
Total Apr-Sept	-11171.02	10	-11986.87	10

Predicted stream flow for each period is computed by the Equation: $\hat{Y} = (b_o + \sum b_n X^1) \times$ correction factor

[a]Correction factor--The original streamflow data that was used to compute the regression coefficients "b_n" and Y-axis intercepts "b_o" were divided by a factor of 10; therefore to get the actual flow using the coefficients, the predictions must be multiplied by the correction factor of 10 in all cases.

Table 24. Listing of significant variables in order of importance and "r^2" values for each predictive period for the Logan River

	April	May	June	July	August	Sept	Total May-Sept	Total Apr-Sept
1	r12	X_1	X_1	X_1	X_5	X_1	X_1	X_1
2	X_4	r9	p5	p5	r10	r2	r2	r2
3	r8	r10	r9	r9	r9	t6	t6	X_3
4	p2	r12	r2	r2	r2	r12	r12	p1
5	r11	t6	t1	t1	t6	r9	r9	t1
6	r6	X_5	p2	p2	t5	t1	t1	r7
7	r2	X_2	X_3	r12	r12	t5	p2	t5
8	r10	t5	p3	t6	t1	r10	X_5	t6
9	r9	X_3	r10	r10	t2	t2	p5	r2
10	r5	t3	X_4	p3	p2	p2	t5	t3
11	r1	p4	r7	t5	p5	X_5	t2	r9
12	p4	p1	t6	p1	X_1	p4	r10	t4
13	r7	t4	t5	X_3	p6	p6	X_4	p2
14	X_1	r1	r12	p6	p3	p5	X_2	X_5
15	p3	r2	t2	t2	r8	r3	p3	X_7
16	X_2	r7	X_5	p4	r7	r8	X_3	r1
17	t1	r8	X_7	r7	X_3	p3	r7	r4
18	p5	X_4	r8	r11	X_2	X_3	r8	X_2
19	t4	p5	X_2	r8	p4	r7	t3	X_4
20	p1	t1	p6	X_7	X_4	X_2	p1	r3
21	X_3	r3	r11	X_5	r3	X_4	X_7	t2
22	X_5	r4	t3	X_2	r11	X_7	r4	r11
23	t6	p2	r4	t3	X_7	r4	r3	p6
24	X_6	r11	r6	X_6	p1	t3	r11	r8
25	t2	X_7	p1	X_4	r4	r1	p6	p5

Table 24. Continued

	April	May	June	July	August	Sept	Total May-Sept	Total Apr-Sept
26	X_7	p6	X_6	r3	t3	p1	t4	p3
27	p6	p3	t4	r5	r1	r11	r1	p4
28	r4	X_6	r1	t4	X_6	r6	X_6	r5
29	r3	r6	r3	r4	t4	X_6	r6	r6
30	t5	r5	r5	r1	r5	r5	r5	r10
31	t3	t2	p4	r6	r6	t4	p4	X_7
r^2_{31}	0.861	0.927	0.960	0.975	0.966	0.958	0.971	0.972
r^2_{15}	0.802	0.859	0.914	0.950	0.923	0.928	0.930	0.941

Table 25. Regression coefficients "b_n" for the Blacksmith Fork River with the number of variables as shown

	April	May	June	July	August	Sept	Total May-Sept	Total Apr-Sept	Total May-Sept
b_1	0.049	-0.080	-0.168	-0.072	0.012	-0.074	0.612	0.661	-0.480
b_2	0.165	0.084	0.067	0.035	0.082	0.017	0.886	1.051	0.328
b_3	2.820	1.245	0.285	0.229	0.584	0.062	3.552	6.372	2.341
b_4	-4.976	1.040	1.789	0.541	-1.815	0.435	-10.873	-15.848	1.935
b_5	-2.073	3.170	-0.805	-0.495	-0.191	-0.250	-0.372	-2.445	2.069
b_6	2.118	-4.870	1.713	1.311	5.798	0.794	24.705	26.823	3.541
b_7	8.203	10.722	-5.738	-2.395	-9.803	-1.665	-46.050	-37.847	-4.816
b_8	-8.450	-17.119	4.052	1.159	7.282	1.107	38.903	30.453	-6.152
b_9	-4.957	-3.248	-5.702	-2.042	04.559	-1.225	-36.949	-41.906	-16.514
b_{10}	1.993	7.966	3.067	1.506	2.740	0.740	25.210	27.203	15.840
b_{11}	0.959	-6.003	-0.942	-0.208	1.195	0.075	4.161	5.120	-5.911
b_{12}	3.312	2.053	2.235	1.027	0.254	0.664	4.733	8.045	6.787
b_{13}	11.338	91.793	14.253	9.764	-21.290	4.162	17.618	28.954	120.311
b_{14}	-26.421	4.156	-8.213	-4.472	-14.818	-1.015	-110.408	-136.830	-16.276
b_{15}	3.049	-23.593	-11.356	-4.767	9.926	-2.044	-25.892	22.843	-35.147
b_{16}	18.207	10.070	24.077	6.985	7.209	3.906	105.380	123.588	55.417
b_{17}	28.214	10.420	27.395	10.690	9.647	8.771	113.513	141.728	75.190
b_{18}	-52.849	-93.884	-34.101	-18.585	-10.485	-8.477	-311.399	-364.250	-179.632
b_{19}	-------	-4.445	-26.340	-6.089	-15.959	-6.207	-------	-------	-55.416
b_{20}	6.962	149.197	37.869	23.375	20.313	11.815	322.295	329.258	250.254
b_{21}	-13.620	-39.871	-26.687	-10.136	-8.447	-5.802	-109.031	-122.651	-103.867
b_{22}	-6.363	-36.241	1.409	-3.446	-7.004	-1.173	-97.464	-103.828	-56.626
b_{23}	48.991	-29.672	35.870	15.965	19.968	13.090	35.910	84.902	54.784
b_{24}	-24.967	60.703	-22.125	-10.194	-3.862	-10.102	66.876	41.909	-65.390
b_{25}	70.330	53.501	20.604	8.289	-8.729	5.979	-48.778	21.551	66.401

Table 25. Continued

	April	May	June	July	August	Sept	Total May-Sept	Total Apr-Sept	Total May-Sept
b_{26}	-9.203	38.659	-19.720	-13.714	-6.944	-5.449	-66.245	-75.448	-3.747
b_{27}	12.940	10.716	0.882	5.877	-5.975	3.292	-74.13	-61.772	10.353
b_{28}	-25.890	-20.050	28.775	12.775	27.477	8.893	96.705	70.815	59.065
b_{29}	96.096	226.897	123.921	60.098	22.208	40.892	367.698	463.793	496.755
b_{30}	119.364	-121.470	-90.532	-38.678	-2.985	-18.825	-101.568	17.795	-291.544
b_{31}	-36.592	4.012	41.272	16.284	64.753	16.025	385.798	349.207	58.727
b_{32}	-3.301	-365.963	-63.404	-42.201	-1.185	-22.184	-185.129	-188.431	-555.589
b_{33}	119.880	7.112	109.660	56.588	10.322	28.941	848.049	967.931	947.771
b_{34}	-105.798	74.826	-185.540	-65.947	-32.706	-58.193	-72.827	-178.625	-355.550
b_{35}	-------	479.869	117.205	70.752	-46.250	38.171	-------	-------	745.262

Table 26. Regression coefficients "b_n" for the Blacksmith Fork River using the 15 most significant variables

	April	May	June	July	August	Sept	Total May-Sept	Total Apr-Sept
b_1			-0.184			-0.048	0.402	
b_2								
b_3	2.388			0.154	0.278		1.351	2.553
b_4	-4.355		1.129		-0.582	0.281		
b_5		6.729						
b_6					2.375			16.567
b_7	9.476				-3.189		-16.177	-32.226
b_8	-10.771	-9.453			1.623		19.089	18.141
b_9		-4.573	-2.220	-1.290	-1.616	-0.361	-12.909	-25.176
b_{10}		9.187		1.527	1.346		13.256	19.742
b_{11}		-5.358			0.763			
b_{12}	2.291	1.952	1.832	0.529		0.672		4.853
b_{13}		86.603	25.991	16.756		7.814		
b_{14}	-14.976				-4.609		-53.216	-86.597
b_{15}				-9.425	3.357		-59.634	
b_{16}			13.948				26.509	
b_{17}	14.448		18.912	9.757		10.940	64.311	84.748
b_{18}	-30.585	-83.257	-14.539	-15.357		-6.736	-137.233	-254.174
b_{19}			-34.152		-4.225	-10.888		
b_{20}		127.189		10.529			146.491	219.380
b_{21}								
b_{22}		-55.264						-90.613
b_{23}	21.769		36.635		9.442	13.948		
b_{24}						-7.442		
b_{25}	44.263					6.618		

Table 26. Continued

	April	May	June	July	August	Sept	Total May-Sept	Total Apr-Sept
b_{26}								
b_{27}	20.199							
b_{28}	-35.012		27.007	8.838	15.692	8.517		
b_{29}	41.890	204.706	113.752	47.850	24.358	29.672	200.626	331.368
b_{30}	127.167	-148.399	-76.420					
b_{31}				27.787	26.448	15.263	294.174	341.249
b_{32}		-425.866						
b_{33}	101.559	648.958		52.067			336.703	532.071
b_{34}			-191.341	-27.754		-67.337		
b_{35}		323.010	41.161	41.790				

Table 27. The "b_o" value and correction factor for each predictive period for the Blacksmith Fork River, Utah

	With variables in model shown in ( ).		With 15 most significant variables in model	
Predictive Period	"b_o"		"b_o"	
April (33)	233.04	10	440.63	10
May (35)	-3357.20	10	-3876.35	10
June (35)	419.23	10	-407.47	10
July (35)	-113.06	10	-825.39	10
Aug (35)	1832.32	10	-15.95	10
Sept (35)	-81.13	10	-54.87	10
Total May-Sept (35)	-2616.79	10	-------	--
Total May-Sept (33)	4830.00	10	2815.93	10
Total Apr-Sept (33)	5063.19	10	6123.82	10

Table 28. Listing of significant variables in order of importance and "r^2" values for each predictive period for the Blacksmith Fork River

	April	May	June	July	August	Sept	Total May-Sept	Total Apr-Sept
1	X_6	X_1	X_9	X_1	X_9	r12	X_1	X_1
2	p3	p1	t7	r10	r11	X_4	r8	r12
3	r4	t1	r12	p1	X_4	p6	t6	t6
4	X_8	p5	p6	t1	r3	t5	p3	t2
5	t2	r10	X_4	p7	r7	t7	t2	p3
6	p2	p7	t5	t3	r10	X_9	r9	t5
7	r7	p4	t1	p5	p1	r4	r10	r9
8	r8	r11	p1	t6	r6	r1	t5	r6
9	r12	r5	r4	r12	r9	p1	r7	r10
10	X_4	r8	r9	t5	r8	t1	r1	r7
11	X_9	t6	r1	p3	p3	t6	t3	r8
12	t6	p2	p2	r9	t2	r9	p5	p1
13	t5	r12	t4	r3	r4	X_6	r3	p5
14	p5	X_3	p7	X_9	t3	X_5	p1	r3
15	p1	r9	t6	p6	t7	p3	t4	X_3
16	t1	r3	t3	X_4	p7	p6	r12	t4
17	r9	X_7	r10	t4	X_1	p2	X_8	r2
18	p6	X_5	p5	X_2	X_7	t4	X_2	r4
19	X_5	p6	r7	p2	t1	p5	X_9	p4
20	r10	X_4	p4	p4	t5	r10	r11	X_9
21	t4	r7	X_2	X_5	X_2	p4	r2	r1
22	r2	r6	X_1	r5	r2	X_1	r4	X_8
23	X_2	t3	X_5	t7	t4	X_2	r6	X_2
24	r11	X_2	p3	t2	X_6	r7	X_3	r11
25	r1	X_6	X_6	X_7	p6	X_8	X_7	X_3

Table 28. Continued

	April	May	June	July	August	Sept	Total May-Sept	Total Apr-Sept
26	r5	t4	r3	X_6	X_8	t3	X_5	p6
27	p3	r2	X_7	r4	X_3	X_7	X_6	X_7
28	X_7	t5	r8	r1	t6	r5	p4	X_5
29	r6	X_9	t2	X_8	r12	r8	X_4	t3
30	X_3	X_8	r2	r7	p5	r6	p2	t1
31	t3	p1	r6	r2	X_5	r2	p6	r5
32	X_1	r4	r5	r6	r1	r3	t1	X_6
33	p4	t2	X_3	r8	r5	t2	t5	p2
34	--	t7	X_8	X_3	p2	r11	--	--
35	--	p3	r11	r11	p4	X_3	--	--
r^2t	0.935	0.980	0.972	0.985	0.965	0.982	0.943	0.957
$r^2 15$	0.914	0.936	0.914	0.947	0.926	0.953	0.887	0.919

APPENDIX B

Data

Table 29. April 1 Water Content of Snow at Nine Snow Courses (inches)

Year	X_1 Franklin Basin	X_2 Tony Grove Lake	X_3 Tony Grove Station	X_4 Spring Hollow Lower	X_5 Spring Hollow Upper	X_6 Mount Logan	X_7 Garden City	X_8 Monte Cristo	X_9 Dry Bread Pond
1924	25.1	31.8	10.0	15.3	21.8	25.8	15.5	23.2	17.2
25	28.3	35.5	0.0	16.1	27.3	32.1	20.7	25.7	19.2
26	18.4	21.9	0.0	9.4	17.6	22.0	12.3	17.8	13.1
27	33.8	43.5	8.5	19.3	31.5	40.8	27.9	30.1	22.6
28	30.0	34.9	0.0	11.0	23.3	31.6	20.3	27.1	20.3
29	31.1	41.7	11.4	17.3	28.9	35.0	23.1	21.7	20.9
1930	26.8	31.5	9.4	12.2	20.7	28.5	17.7	14.6	18.3
31	14.9	15.0	3.6	8.3	12.9	18.3	7.0	6.5	10.9
32	38.6	54.2	16.1	24.3	36.5	42.3	27.4	20.2	25.6
33	28.2	38.4	13.1	15.5	25.4	28.4	16.2	19.4	19.1
34	12.6	19.2	0.0	0.0	14.2	18.8	2.3	7.0	9.5
35	24.4	29.1	8.6	14.5	28.9	27.9	17.9	16.4	16.8
36	39.7	50.5	23.5	20.6	35.5	38.3	31.9	39.6	22.1
37	20.8	32.5	15.2	16.2	25.0	27.4	16.5	18.8	13.3
38	24.9	36.5	11.4	14.5	28.7	29.2	20.2	30.7	23.6
39	20.4	25.2	5.5	8.5	19.4	20.8	16.4	20.3	11.5
1940	21.8	27.0	2.0	8.1	20.5	23.5	10.6	17.6	10.7
41	15.4	21.7	4.6	9.8	18.4	19.4	11.7	17.4	11.6
42	17.8	23.3	7.8	12.6	21.4	22.5	12.1	18.2	12.7
43	38.8	54.9	17.6	17.9	35.8	41.3	28.5	32.7	26.1
44	20.2	20.5	6.8	11.5	17.5	18.5	9.9	18.3	12.9
45	19.8	27.3	10.5	12.0	20.2	22.8	13.6	23.9	18.0
46	30.2	37.4	8.1	16.0	30.0	36.1	24.1	30.6	18.7
47	23.3	28.0	3.8	9.9	24.4	25.8	14.0	24.0	16.0
48	26.5	34.2	8.9	13.9	23.8	26.4	16.2	22.0	18.1
49	30.5	39.5	10.1	17.3	31.0	34.6	23.6	31.1	22.8

Table 29. Continued

Year	X_1 Franklin Basin	X_2 Tony Grove Lake	X_3 Tony Grove Station	X_4 Spring Hollow Lower	X_5 Spring Hollow Upper	X_6 Mount Logan	X_7 Garden City	X_8 Monte Cristo	X_9 Dry Bread Pond
1950	41.3	50.3	14.0	19.8	34.7	41.9	29.3	36.0	27.0
51	32.8	52.0	15.1	14.6	30.4	37.4	25.3	31.4	21.1
52	40.2	47.6	17.6	24.5	34.6	43.8	26.6	39.2	31.3
53	23.7	35.5	6.7	11.3	22.3	26.0	15.0	23.4	16.2
54	23.3	27.5	7.5	15.0	24.1	27.9	20.0	22.3	14.7
55	23.8	28.0	11.2	15.8	23.3	27.6	15.7	26.9	20.1
56	31.8	42.5	8.4	11.8	31.5	34.8	21.9	31.6	20.3
57	31.6	42.0	9.5	16.1	28.1	30.5	21.0	25.7	19.0
58	31.5	42.0	13.4	11.0	30.0	33.8	22.8	31.5	22.0
59	24.9	32.7	9.6	12.3	19.9	23.1	16.0	20.0	12.9
1960	22.1	29.0	9.2	12.1	20.4	24.6	14.0	19.9	15.5
61	21.0	25.9	6.3	12.8	19.6	23.2	12.9	17.9	11.8
62	32.0	44.2	12.8	18.1	32.8	37.4	23.4	33.0	23.3
63	21.1	28.0	4.1	0.0	16.0	22.7	13.1	19.7	13.4
64	25.2	30.1	12.2	14.4	20.8	24.0	16.0	23.4	16.4
65	39.4	52.0	13.8	17.9	33.1	39.7	25.8	29.4	19.0
66	22.2	29.8	7.5	9.6	21.8	25.2	14.8	23.2	14.7
67	28.3	38.3	9.1	16.7	24.4	30.4	19.2	23.1	16.1

Table 30. The Linear Regression Equation and Linear Correlation Coefficient of Mount Logan Snow Course Data versus Garden City Summit Snow Course Data

Observations	Year	X Mount Logan (in.)	Y Garden City (in.)	$x=X-\overline{X}$	$y=Y-\overline{Y}$
1	1931	18.3	7.0	-10.79	-11.19
2	32	42.3	27.4	12.91	9.21
3	33	28.4	16.2	-0.69	-1.99
4	34	18.8	2.3	-10.29	-15.89
5	35	27.9	17.9	-1.19	-.29
6	36	38.3	31.9	9.21	13.71
7	37	27.4	16.5	-1.69	-1.69
8	38	29.2	20.2	0.11	2.01
9	39	20.8	16.4	-8.29	-1.79
10	1940	23.5	10.6	-5.59	-7.59
11	41	19.4	11.7	-9.69	-6.49
12	42	22.5	12.1	-6.59	-6.09
13	43	41.3	28.5	12.21	10.31
14	44	18.5	9.9	-10.59	-8.29
15	45	22.8	13.6	-6.29	-4.59
16	46	36.1	24.1	7.01	5.91
17	47	25.8	14.0	-3.29	-4.19
18	48	26.4	16.2	-2.69	-1.99
19	49	34.6	23.6	5.51	5.41
20	1950	41.9	29.3	12.81	11.11
21	51	37.4	25.3	8.31	7.11
22	52	43.8	26.6	14.71	8.41
23	53	26.0	15.0	-3.09	-3.19
24	54	27.9	20.0	-1.19	1.81
25	55	27.6	15.7	-1.49	-2.49
26	56	34.8	21.9	5.71	3.71
27	57	30.5	21.0	1.41	2.81
28	58	33.8	22.8	4.71	4.61
29	59	23.1	16.0	-5.99	-2.19
30	1960	24.6	14.0	-4.49	-4.19
31	61	23.2	12.9	-5.89	-5.29
32	62	37.4	23.4	8.31	5.21
33	63	22.7	13.1	-6.39	-5.09
34	64	24.0	16.0	-5.09	-2.19
35	65	39.7	25.8	10.61	7.61
36	66	25.2	14.8	-3.89	-3.39
37	67	30.4	19.2	1.31	1.01

Table 30. Continued

Total	1076.30	672.90	x^2=1989.66	y^2=1569.14
Mean	29.09	18.19		
			$\sum xy$=1656.12[17]	

The linear regression equation:

$$\hat{Y} = b_o + b_1 X$$

$$b_1 = \frac{\Sigma xy}{\Sigma x^2} = +0.832$$

$$b_o = \overline{Y} - b_1 \overline{X} = -6.01$$

$$\hat{Y} = -6.01 + .832X$$

The linear correlation coefficient:

$$r^2 = \frac{(\Sigma xy)^2}{\Sigma x^2 \Sigma y^2} = 0.8785$$

$$r = .9374 = 93.74\%$$

Table 31. New Gypsum Soil Moisture Data (average, antecedent, October reading in milliamperes) and the Deviations of the Observed and the Predicted Streamflow for the April through September, total, Predictive Period for the Logan River, Utah.

Year	Tony Grove Ranger Station N. G.[a]	Klondike Narrows N. G.[a]	Deviations April-Sept. (Acre-feet)
1958	-----	122.2	-14,500
59	61.4	67.9	3,820
1960	86.2	152.3	4,630
61	17.5	102.8	-5,590
62	38.8	127.6	3,700
63	10.8	126.9	4,460
64	94.0	172.4	-9,930
65	89.0	51.7	5,160
66	118.7	183.3	-330

[a]New gypsum soil moisture blocks

APPENDIX C

Figures

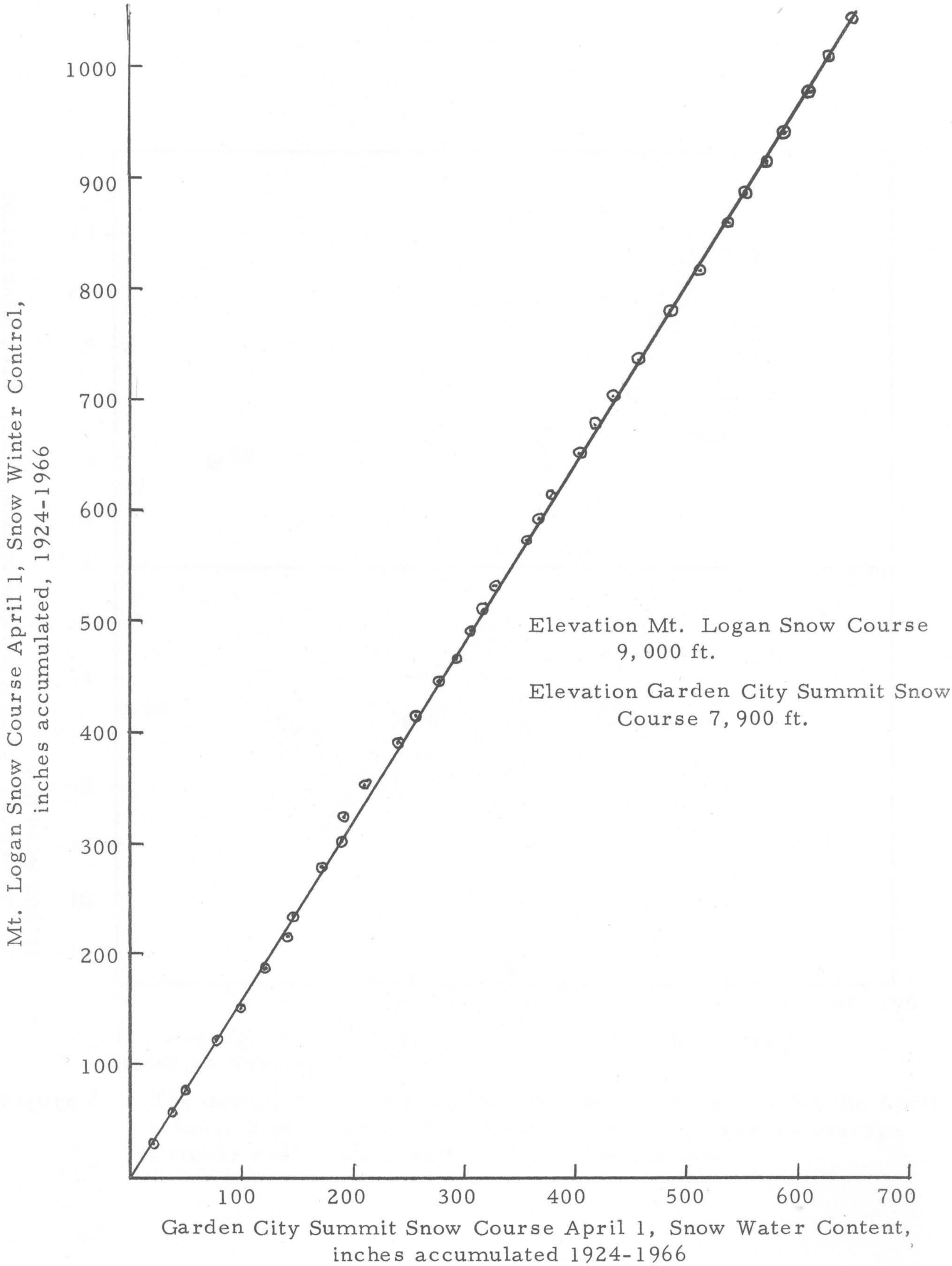

Figure 1. Double mass curve of Mt. Logan snow course data versus Garden City Summit snow course data

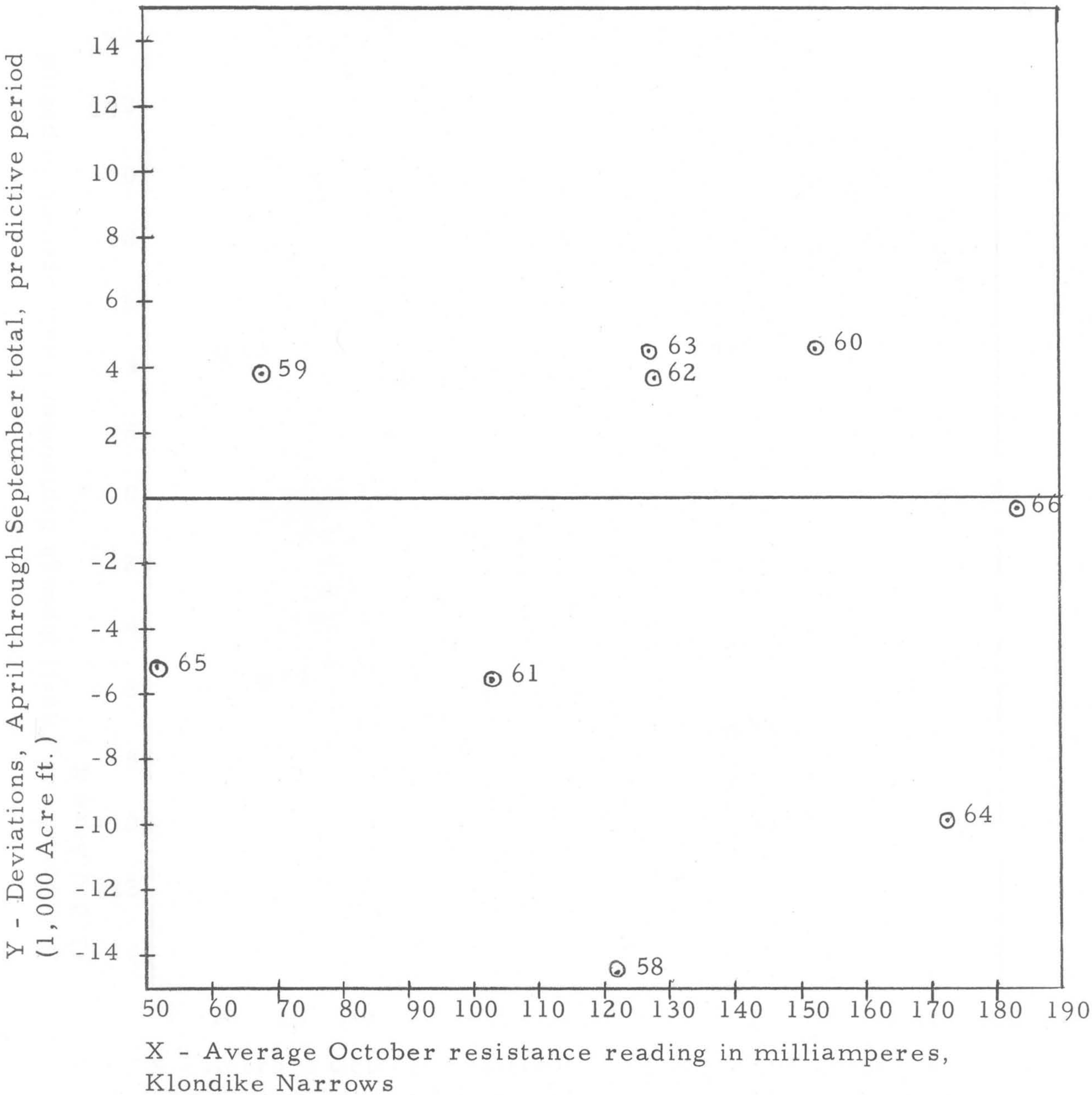

Figure 2. The deviations of the predicted and the observed flow for the April through September total, predictive period, versus the average October resistance reading at Klondike Narrows

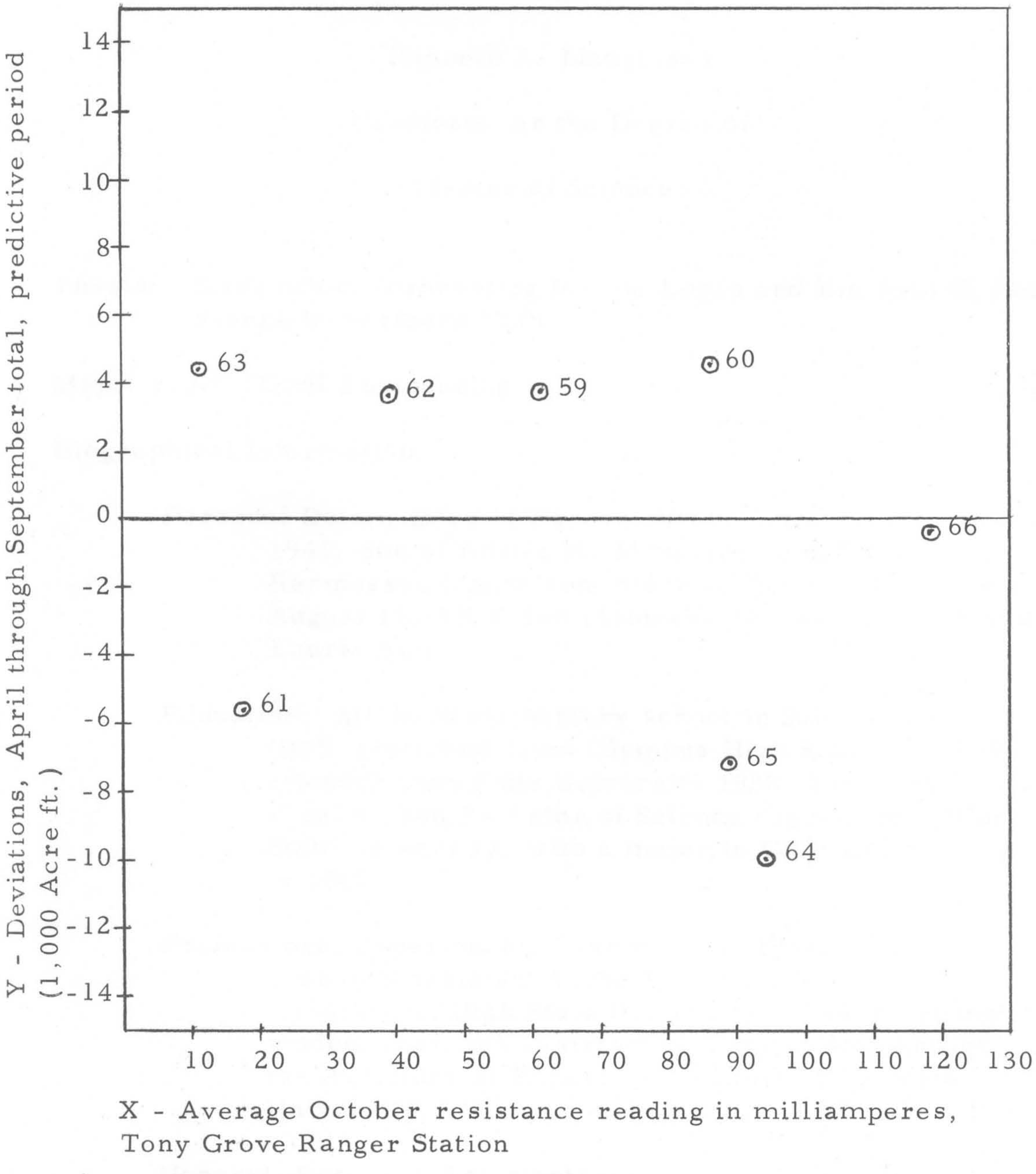

Figure 3. The deviations of the predicted and the observed flow for the April through September total, predictive period, versus the average October resistance reading at the Tony Grove Ranger Station

VITA

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Master of Science

Thesis: Streamflow Forecasting for the Logan and Blacksmith Fork Rivers in Northern Utah

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